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Gorrie, Robert MacLagan

The use and misuse of land.

(OXFORD FORESTRY MEMOIRS

Number 19, 1935)

THE USE
AND
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BY

R. MACLAGAN GORRIE, D.Sc., F.R.S.E.

*Indian Forest Service; Leverhulme
Research Fellow*

OXFORD
AT THE CLARENDON PRESS

1935



Erosion caused by a road culvert, San Gabriel, Southern California



Sheet erosion follows destruction of vegetation by grazing in Navajo Indian Reservation; wire and canvas dam catches 10 inches depth of silt on a wide front

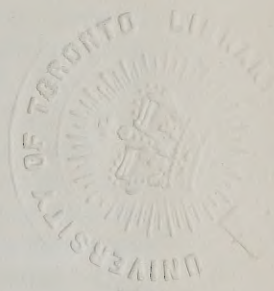
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OXFORD UNIVERSITY PRESS
AMEN HOUSE, E.C. 4
LONDON EDINBURGH GLASGOW NEW YORK
TORONTO MELBOURNE CAPE TOWN BOMBAY
CALCUTTA MADRAS SHANGHAI
HUMPHREY MILFORD
PUBLISHER TO THE UNIVERSITY



PRINTED IN GREAT BRITAIN

PREFACE

THE following report has been prepared from material collected during a four months' tour of the United States, which was rendered possible through the generosity of the Leverhulme Research Fund. The subject for which this research fellowship was awarded was: 'The Correlation of Erosion Damage and Grazing in Forest Lands,' but the report now presented deals in addition with the somewhat wider implications of the misuse and abuse of forest land and the need for a well-considered land policy to prevent this. It is felt that if the land as a whole could be put to its best uses, and if backward agricultural communities were helped towards this aim, the menace of over-grazing would automatically disappear. The question of erosion control on farm land has also been dealt with as it is felt that recent American developments should be of value to workers in this field, particularly in Africa and India wherever 'shifting cultivation' is still practised.

Previous experience in erosion problems has been gained as a student in Switzerland and the Haute Savoie, and subsequently during 12 years' service as a forest officer in various parts of Northern India, entailing the study of grazing and erosion problems in the plains, the foot-hills, and the inner Himalayas.

I wish to acknowledge a very great debt of gratitude to the many American foresters and officials without whose continuous kindness and ungrudging help it would have been impossible to attempt my 17,500-mile tour. The Chief Forester and the Director of the Soil Erosion Service both placed the resources of their departments at my disposal. My programme was sponsored by Mr. W. R. Chapline, head of the Range Research Branch of the Federal Forest Service, who took endless trouble in organizing the details of the tour and supplying me with much information. During the course of the tour the Forest and Range Experiment staffs of the Appalachian, California, Intermountain, Lake States, Northern Rocky Mountain, and South Western Stations were all most helpful, likewise the British Columbia and New York State foresters, the Tennessee Valley Authority's forest staff, the forestry faculties of Berkeley, Tucson, and Yale Universities, and the staffs of the Department of Agriculture farms and Soil Erosion Service projects in Arizona, California, Montana, North Dakota, South Carolina, Texas, Washington, and Wisconsin.

I also wish to acknowledge the assistance of the Imperial Forestry Institute, Oxford, and the Imperial Bureau of Soil Science, Harpenden, in obtaining library facilities and references, and the advice and encouragement given by Professor R. S. Troup in planning the tour and this report.

R. M. G.

OXFORD
22 February 1935

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SUMMARY

The Use and Misuse of Land

1. MUCH of the land classified as 'forest' in the arid tropics and the semi-tropics in British dominions and possessions is incapable of producing crops of commercial timber, but is of considerable social value for grazing, flood control, water conservation, or game management, which would justify some form of working plan being prepared and operated with these values in view.

2. In the United States similar problems have arisen and have been dealt with by the Federal Forest Service. Range management and grazing research have formed part of its responsibilities for twenty-five years, and considerable work has also been done on the organization of forests for stream-flow control, game management, and as public playgrounds. The reports and actions of such bodies as the National Resources Board, the Mississippi Valley Committee, and the Tennessee Valley Authority have all emphasized the need for handling forestry problems as part of a well considered land policy, in which the local need for shelter-belts, fuel and timber reserves, and grazing areas is integrated with local agricultural production, while the wider aspects of commercial timber production, water supply, flood control, game protection, and recreation have also to be included. The experience thus gained and the improvements and developments so far made should be of some interest and value to those handling similar problems of land management in other countries.

3. In the use of wild lands for grazing the main points to be emphasized are, firstly, to determine what number of stock the ground will support without spoiling the carrying capacity for that type and, secondly, to see that the figure is enforced. Where grazing is excessive, every effort should be made to reduce it; where religious beliefs interfere with the disposal or reduction of cattle, as in Hinduism, it is particularly necessary to show by practical demonstration and education the evil effects of overgrazing.

4. Over-grazing in arid areas is a primary cause of accelerated soil erosion, leading inevitably to destructive floods and the silting up of irrigation and town water-supplies. Owing to the need for providing work for their unemployed, the United States have undertaken very large works for the control of soil erosion through the agency of the Forest Service, the Soil Erosion Service, and the Tennessee Valley Authority, so that a large amount of fresh data on the processes and control of erosion is now available for the first time.

5. The high value of water supplies for the innumerable irrigation projects and city water requirements in California and the Western States generally has forced the development of a technique in water saving and stream-flow measurement, and a recognition of the important role of vegetational cover in efficient water conservation, particularly under arid conditions. Considerable progress has recently been made in establishing the exact source of disastrous floods, and the comparative water-saving value of the different types of vegetational cover under various methods of land management.

An alarming feature of the American situation as regards their vast chain of irrigation reservoirs is the rapidity with which these are being silted up by the accelerated erosion from their catchment areas, many of which are publicly

owned upland grazing lands. Many of these reservoirs are losing their storage capacity at a rate of over 1 per cent. per annum, which will not only ruin the commercial prospects of the project in much less than 100 years, but will render unstable these new and promising irrigation colonies, leading to further unemployment and social drifting in what ought to be a stable community. Similar irrigation projects are already under way or contemplated in many British countries, and this danger to their success should be guarded against by early action in the careful preservation of vegetational cover in the catchment areas.

6. The role of forests as an important item in the economy of the agricultural village or farm community has been emphasized by the discussion of a proposed shelter-belt project for the arid Prairie States. A somewhat similar problem awaits the forester in India and other Oriental countries where the crying need is for village fuel plantations, because only a cheap and plentiful supply of fuel will stop the present wasteful custom of burning cowdung, thus destroying what ought to be going back into the soil as manure.

7. The loss of soil from farm depletion through the use of bad farming methods, and through breaking for cultivation large areas of forest and prairie grasslands which are basically incapable of producing paying farm crops, is a far more serious matter than is generally recognized. The National Resources Board estimates the average annual loss of organic matter from crop and pasture land in the United States as 322,000,000 tons, and a loss of 50 to 60 tons of soil per acre per annum has been verified in certain types of wheat and maize cultivation. The Soil Erosion Service, established in 1933 under the Department of the Interior, is engaged in farm erosion control on a national scale in selected demonstration units in areas suffering most heavily. The programme includes contour terracing and strip cropping in fields, check dams and revegetation in waste land, and reforestation of woodlands which have deteriorated or been destroyed through grazing or shifting cultivation, which in its most primitive form is still practised in some parts of the States. Although Oriental cultivation methods have conserved the soil of fields more carefully than the pioneering phase of American farming, there is nevertheless great scope for the teaching of soil conservation amongst farming communities, particularly in climates subject to sudden torrential downpours. Wherever shifting cultivation is still the established agricultural method, the need should be recognized for placing the forest upon a permanently productive footing as the basic agricultural resource.

8. Other examples of the gross abuse of land are seen in: (i) Covering large areas of valuable riverain silt in the gold belt of the Californian Sierras with sterile stone debris from hydraulic gold crushers. (ii) Poisoning all vegetation in the neighbourhood of copper smelters in California, Arizona, and Tennessee by the emission of sulphur dioxide fumes; the killing off of the vegetation is quickly followed by intense sheet erosion and later by gullying. (iii) Lack of planning in the drainage of roads frequently leads to intense erosion.

9. The proper agency for holding and developing land and preventing such abuses is a small but representative public body with sound technical advice at its disposal and sufficient powers to enforce the decisions it arrives at. Private ownership and the common use of 'waste' land has almost invariably over-worked one use and neglected other possibilities, failing to develop the multiple

use principle which can best serve the community as a whole. This is particularly true of the enormous areas of village grazing or common lands in British tropical countries where urgent action is necessary to prevent further misuse and conserve what is left of the soil's natural resources. Such action can obviously not be undertaken by the villagers themselves without some help from government, and authorities are therefore advised to initiate the demonstration of better land-use practice and organize local land-use councils.

Note. A bibliographic list of numbered references is given at the end of each chapter.

I. FORESTRY AS A FACTOR IN LAND MANAGEMENT

Forestry as Part of a Larger Picture.

ANY assessment of a nation's resources must automatically involve an account of its timber wealth, because a deficit in home-grown timber entails expensive imports from abroad. From other and less obvious points of view, however, it is desirable to make known the value of forests to the community. An examination of recent reports on national resources, such as the American National Resources Board of 1934 (1) and the Royal Commission on Agriculture for India of 1928 (2), shows very clearly how closely forestry and the allied land uses are interrelated, and how numerous are the indirect effects of the presence or absence of forests to the community. Particularly in arid climates, water is the limiting factor in all forms of cultivation, and the available and usable total of water, whether for irrigation or for community water needs, depends in most cases upon the vegetational cover of the catchment areas.

Soil erosion and its control by revegetation are, on the other hand, equally subject to the local water supply, so that the two problems of land and water utilization are only phases of one larger science whose primary object should be the optimum use of all the natural resources of a country for the maximum benefit of its population as a whole. Land-use planning with this object in view can only be done efficiently and wisely after consideration of such diverse but interrelated activities as agriculture, industry and labour, transport and communications, health and education, governmental activities and public funds. The human and social values are far more significant and important in the end than the values of land, water, and minerals upon which they largely depend, because the well-being of the community as a whole should be the ultimate and continued aim of all such land management. It is therefore a task which calls for the devoted and unselfish service of the best brains in the community.

The amount of land to be devoted to timber production is really only the beginning of forestry when land planning on such a basis is contemplated. To quote the National Resources Board Report: 'Forest land requirements cannot be judged merely in terms of needs for timber or other tree products. Forests are important for regulating stream-flow, preventing erosion, and providing protection against wind. They provide a habitat for wild life, and have large possibilities for outdoor recreation. They are interrelated to agriculture and are an important factor in scenic, recreational, and economic interests of innumerable localities.'

The Present Land Situation in the United States.

To understand the present position of land in America, with millions of acres of inferior agricultural land going out of cultivation, and further millions of acres of forest land previously in private ownership lapsing back into government ownership through 'tax delinquency', it is necessary to realize that the country is only now emerging from the pioneering stage, in which each decade saw a fresh movement westwards to develop hitherto virgin territory, with government actively encouraging fresh settlement with the parcelling out of land claimed by homesteaders who had only to take possession of it, and the

distribution of enormous areas to railway companies which undertook to open up the country with new lines. The opening up of the arid Middle West, which was naturally covered with a prairie grassland of rather widely spaced perennial bunch-grass, led to the development of a 'dry-land farming' technique, which served excellently for a few years of high wheat prices and rains above the average intensity. Rapid desiccation has, however, followed the breaking of the prairie sod, and wind erosion is responsible for a very appreciable loss of the loosened top-soil; in fact the dust storms of the summer of 1934 were an example of wind erosion on a gigantic scale. The powdery top-soil lifted from a vast acreage of ploughed prairie land was carried hundreds of miles eastwards to become a nuisance in cities of the Atlantic seaboard which had never previously experienced a dust storm.

Poorer crop yields combined with the general fall in prices have made the dry-land farming throughout the Middle West definitely uneconomic. Again, in areas of more favourable rainfall in the east and west there are very large tracts of poor land which should never have been broken up for cultivation, as they are fit only for fuel coppice or rough grazing. These are the so-called 'sub-marginal lands'—i.e. they are below the soil fertility standard at which economic farming is possible. The National Resources Board visualizes retiring 5 million acres a year out of cultivation at a cost of 5 to 6 dollars per acre. It is not difficult to find such areas in any country, and, wherever it is at all possible to transplant these farmers to more productive areas, it is advisable to do so, allowing the land thus released to go back to forest or some form of extensive stock farming.

The proposed Prairie States shelter-belt, which is discussed in Chapter V, is merely a palliative and costly method of correcting and alleviating to some degree the damage already done by breaking the prairie sod over vast areas of the Middle West. In spite of the obvious benefits which will be derived from farm shelter-belts wherever they can be established, wind erosion in that very arid region will doubtless continue through periods of drought so long as the top-soil is loosened and pulverized by cultivation. The best solution for much of this desiccated region would be to take it out of cultivation entirely, restore it to a grass cover, and ensure that this is preserved by allowing only the very lightest grazing. This, however, is hardly feasible with such a large farm population on the ground, and certainly less practicable than the Shelter-belt project, as the fuller discussion of this item in Chapter V will show. The project as at present under consideration by the United States authorities would be of great value to the farming community, even though it does not satisfy all the needs of a radical replanning of economic land uses. The prairies are essentially a bunch-grass country, and are unlikely to prove profitable, or support a permanent population, under any other form of management than grassland.

As regards the tax-delinquent forest land, only about a quarter of the total forest area of 615 million acres belongs to government, the bulk having been taken up as private timber holdings by lumber companies, which are as a rule prepared to pay their annual land tax only on such forest land as they have not yet cut over, and avoid doing so on logged land in which they have no further interest. There are thus very large areas of wrecked forest lands interspersed with scattered farms which are likely to be permanently tax delinquent. The

government is thus being forced into taking over such areas, and the reorganization and land-use planning for these areas whose natural resources have been exhausted constitutes a huge problem. The land acquired by the Federal Government will be included in adjacent national parks, game refuges, and forests, or leased to individual State administrations for these objects, or will be formed into co-operative grazing units when in suitable areas. Efforts are also being made to adjust taxation and persuade timber owners by this and other means to reduce fire losses and maintain their forests on a basis of sustained yield. In countries where the bulk of the forest land is government owned, this unpleasant situation need not arise, but where it has arisen, it points to the fact that some form of government control must sooner or later be enforced upon common right areas and privately owned land, where the owners are robbing the land of its natural resources, as in the over-grazing of public or village land, or causing it to become a source of public nuisance, as in the Davis County (Utah) Flood Control problem discussed in Chapter IV.

An Example of Land Planning Applied Locally.

An excellent example of the local application of land planning in which forestry plays an important part is in the Land Utilization Plan for Eldorado County in the Sierra foot-hills of Northern California (3). Local interest in land planning was first aroused by the California Economic Research Council in 1927, when rapid local changes were taking place following the reduction of the older self-sufficient communities by the improvement in transport and road development, and a general realization by the farmers that the foot-hills were deteriorating rapidly from their previous stock-carrying capacity. A detailed survey of local conditions was carried out by three men—an agricultural economist, a forester, and a specialist in the marketing of forest and range products. Their report has been followed up practically by the formation of a Land Utilization Committee of local residents who have already effected many of the proposed alterations. The extension of irrigation is controlled by a private company, but this has placed its policy in the hands of this committee for advice. The State of California has no constructive policy in land uses; its one anxiety is to re-sell as quickly as possible all tax-delinquent land it can get rid of, as unoccupied land means no taxes coming in. Any constructive action must therefore depend upon local organizations.

Description of Eldorado County Problems.

Eldorado County, which the report covers, is an area of just over a million acres with a population of a little over 8,000. About 600,000 acres of it are inside National Forest, and over 300,000 acres are in farms, but of this only 20,000 are under crops, the rest being rough foot-hill grazing. Typical of almost the whole length of the Sierra foot-hills and their wider problems of gradual deterioration through fire and other abuses, this area is serving as a demonstration area for what can be accomplished in organized planning. It extends eastwards from the plains of the Sacramento Valley across the gradually rising foot-hills to the higher mountain forests and lake-lands at the bend in the straight eastern boundary of California. The forests, certain minerals, recreational opportunities for the coastal urban populations of San Francisco Bay,

water power, grazing land, and a limited amount of agricultural crop land, form its chief natural resources. The population in the early gold-mining days was the largest of any county in the state, but has since been declining. Declining school attendance has followed the failure of many of the scattered farms, and the cost of government and education exceeds the public income in all except urban areas.

A complex live-stock industry depends upon seasonal grazing at different altitudinal levels and also requires supplementary field crops for feeding, so that the uses of the various altitudinal zones have to be co-ordinated. The higher elevations are becoming important as summer recreation centres, and thus recreational and grazing values are coming into conflict. The water supplies from the American and Costumnes rivers are vitally important for the irrigation of several other plains counties to the west, so that soil and water conservation are not merely local problems, but have a much wider implication, though they do not help the local exchequer. Game management is an important item in the national forest administration, for much of the forest revenue comes from game licences, but farms adjacent to forest areas are subject to crop and live-stock losses from deer and other wild animals. On the other hand, wild animals and particularly game birds are liable to dwindle and disappear as civilization encroaches upon their preserves. All these points must be familiar to any forest officer or land administrator with colonial experience, as these or similar problems occur almost everywhere.

Objectives of the Land Plan.

The general objectives of this utilization report are as follows:

1. To obtain for the owners of the land and for the community and the local government the greatest possible return in proportion to the amount of energy and capital applied.
2. To protect farmers from the results of unwise expansion and to give such assistance as may be possible to the efforts being made throughout the county to balance production and consumption.
3. To assist residents in the area to adjust their economic programmes to changing conditions.
4. To conserve for the general public of this and future generations the natural resources, including the soil and its fertility. In the maintenance of these resources in unimpaired productivity the public has an interest superior to that of private exploitation.
5. To provide information concerning adaptations and probable future utilization of lands which will make possible progressively greater efficiency both in land use and in the administration and financing of the several functions of government and public service agencies.

These five objectives might well be taken as the basis for similar work in almost any other country-side with diversified and conflicting interests which have to be co-ordinated. Let us see how the problem has been handled in this instance.

The first step was a soil classification survey, which is an essential basis for any land planning. It may be remembered that the Royal Commission for Agriculture in India considered the need for intensive soil surveys, but on the

score of expense decided that a soil survey for the whole of India was not feasible. What is required is not so much elaborate soil analyses, valuable as these are, but a reasonable method of classification into types or groups. On the basis of previous intensive work on one point in this area the Eldorado report divides the local soils into eight divisions as follows:

Class A, good.

- I. Deep residual soils of medium to heavy texture with heavy-textured subsoils, mostly deep red clay.
- II. Deep residual soils of light texture, of low water-holding capacity, but productive under irrigation, mostly granitic.

Class B, mediocre.

- III. Shallow residual soils, mostly clay loams.
- IV. Stony residual soils.
- V. Shallow, heavy-textured soil, mostly Sierra clay loam not more than 2 feet deep.

Class C, poor.

- VI. Stony shallow soils.
- VII. Rough mountainous land, soil types not differentiated.
- VIII. Serpentine ridges, placer gold diggings, tailing dumps from mines, and other completely infertile areas.

The above is quite sufficiently accurate for the purpose, provided it is used intelligently in conjunction with climatic data and the actual experience of local farmers in estimating the effect of climate, elevation, and exposure upon the ripening of their various crops.

Interactions of Land Uses affecting Grazing.

The fact that the area under crops has dwindled from 31,000 acres in 1863 to the present figure of 19,700 acres, and the many traces of old pear orchards and vineyards in land which has reverted to scrub, show very clearly how ill-advised much of the early orchard-planting must have been. Fruit cultivation here can only be a sound investment where deep and fertile lands are permanently irrigable, for although the rainfall at higher elevations is more than sufficient, the limiting factors of frost, and average temperature during the growing season, limit these crops to the deeper valley soils below 2,000 feet where the rainfall is generally short. The fate of the existing orchards is therefore in the hands of the several private companies which operate small irrigation canals or 'ditches'. These in turn are dependent upon the hill streams, the cost of operation varying directly, and the total irrigable area inversely, with the occurrence of damaging floods and subsequent low levels which are inseparable from any abuse of the catchment areas' vegetation cover. Most of the 'ditches' are incompletely developed, but would require heavy expenditure to make larger water supplies available, and estimates indicate that such expansion would lead to higher costs per acre all round. Any expansion of irrigation would be better employed in providing a better acreage of irrigated pasture to tide the live-stock industry over bad grazing seasons, and it is along this line that irrigation developments are now taking place under the advice of the local committee.

The local grazing resources include extensive areas, both public and private, of grass and browse (palatable shrubs and weeds as opposed to grass) as well as the ranges of the Eldorado National Forest. The latter have been grazed under a conservative permit system for many years, and a balanced grazing incidence has been established which protects the ranges from serious deterioration, but in the lower foot-hills belonging to the county and private owners the situation is deplorable. The summits above 6,000 feet carry mostly good stands of fir and Jeffrey pine, while below this there is much good timber of mixed fir and pine, the most valuable being *Pinus lambertiana* and *ponderosa*. Below this the foot-hills down to about 1,000 feet were at one time covered with a scattered but valuable stand of *ponderosa* pine and black oak (*Quercus kelloggii*) amongst open grasslands and open stands of the less valuable digger pine (*Pinus sabiniana*). These were largely destroyed by the early settlers, and have since been replaced by chaparral scrub, a mixture of low leathery-leaved bushes with no tree growth whatever.

Continuous burning of these foot-hill types of perennial grassland and scattered pine tends to replace both with a dense mass of *chamise* (*Adenostoma fasciculatum*). This has spread, and is still spreading, at their expense, ruining both of them for stock, as it is only edible during its first year, and forming an ever-increasing fire danger, as it is highly inflammable and regenerates profusely after each fire, to the exclusion of all other vegetation. Where the *chamise* has not come in, the perennial grass has been replaced by annual grasses inferior in forage value and by weeds. Any proposals for improvement of this grazing industry cannot be based on the total area used by live-stock, but must rather consider the carrying capacities of vegetational types, the time of year when feed is available, the differing types of farm and size of enterprise, costs of operations and returns, the reaction of the land to the use being made of it, and from this the permanence of the operation. For an 8 months' grazing season with some supplementary feed, capacities vary from 10 acres per cow on the better grasslands to 26 acres on lighter soils with a shorter growing season. On a 12-month basis as much as 40 acres per head is needed.

Local ranching systems hinge upon the availability of summer feed, falling into one of three categories: (i) migratory and entirely grazing; (ii) migratory grazing supplemented by grain straw and irrigated pastures; (iii) non-migratory herds in the foot-hills also depending on crop feed to supplement grazing. The stock is mostly beef and dairy cattle, with some sheep in the higher lands, but the problem with all these types is to secure supplementary feed to tide them over the dry season. Most private ownership is moreover based on one use of the land only, and this single-use outlook compels the owner to sacrifice all opportunities other than the one in which he is engaged. Most of the wild lands supporting these grazing enterprises are, however, capable of yielding more than one product and possibly a combination of timber, grazing, wild game, recreation, or water supply, and it is in a more versatile use of these, rather than the misuse of one, that future prosperity for the foot-hills farmer lies. The report has recommended a more extensive system of grazing utilization, abandoning scattered and uneconomic farms in favour of the consolidation of holdings into larger group enterprises which can thus make better seasonal use of ranges at different elevations, with group action on policies of land clearing, range improvement, and fire control. The grazing management of the 1,000–3,000-foot



A hill-side in the Californian Sierra foot-hills where heavy grazing has destroyed the cover and induced serious gullying. Photo by courtesy of F. G. Renner, California Forest and Range Experiment Station



Cattle range in arid New Mexico in good condition after prolonged drought, thanks to conservative grazing. Jornada Experimental Range

belt is complicated by the excessive fire danger, and the fact that the early summer grass is wanted for all three of the ranching types, so that over-grazing here can only be prevented by correlating the needs of the high level and the low level ranchers. This has been carried out to some extent already along the lines outlined above.

Summary of Recommendations affecting Grazing.

The report condemns the widespread over-grazing which has occurred under private ownership and on uncontrolled public domain; points out the very serious deterioration which has followed three-quarters of a century of indiscriminate burning; and suggests:

- (i) Determine soil classifications and grazing capacities.
- (ii) Consolidate holdings and relocate wild lands to their most economic uses—shallow grasslands for grazing, deeper soils for cultivation and fodder production.
- (iii) Group action by grazing or live-stock associations of owners.
- (iv) Safeguard disforested land for any prospective timber value as well as present grazing value.
- (v) Develop technique for converting best of chaparral-covered wild lands to sown grass crops.
- (vi) Aim at each farm having at least some share in available irrigation.
- (vii) Deal with seasonal fluctuation in feed supply by developing supplementary fodder crops most suitable, hiring of mountain range in summer, and annual sale of stock before worst grazing season comes on.

Recommendations Affecting Forestry.

The growing importance of recreational use of the lake-land district around Lake Tahoe at the highest eastern corner of Eldorado County has introduced a fresh source of revenue to the local population, but the inevitable conflict between holiday-makers and stock-farmers, particularly sheep graziers, has arisen, as campers will not use land soiled by sheep. In areas where both these uses and timber production have to be considered, the simpler combination is of recreation and forestry, subordinating the sheep interest to the other two, as they satisfy the claim of the greatest good for the greatest number. This decision has here been confirmed by the public, who are returning to the Lake Tahoe neighbourhood year by year in greater numbers. The reconciling of conflicting uses can best be brought about by an unprejudiced appraisal of the respective claims, by allowing reasonable compensation to those whose interests are sacrificed, and by active development of alternative sources of income where earnings are threatened by the changes brought about.

Apart from this eastern section adjoining Lake Tahoe, where lumbering work is to be reduced to a minimum in view of the recreational requirements, the remainder of the timber forest is to be developed as fully as possible, consistently with a sustained yield from the remaining virgin timber for the local lumber industry until the oldest second growth, now about 60 years old, will reach timber size.

The Eldorado Land Plan has been dealt with in considerable detail as it is felt that it serves as a demonstration of the best line of attack in dealing with

land-use problems in which forestry and live-stock farming are major items. The Eldorado Plan is a young one, and there are doubtless many other areas in which either forestry or live-stock farming, or both, have been brought to a higher pitch of efficiency. The need for some such combination of land uses has long been recognized (*vide* the old-established forest workers' small-holdings in European countries) and the detailed survey of an area to reconcile land uses with the varying quality of the soil has been carried out more extensively in Britain than in any other country. It is hoped, however, that by enlarging upon the Eldorado method of attack some incentive may be given to forest officers to incorporate in their forest working plans a more detailed consideration of the local grazing situation and soil and water conservation problems, and the correlation of these objectives with the primary one of timber growing. The ideal allocation of land for the community's needs will naturally vary greatly with the standard of living and the stage of industrial and social development; the figures generally accepted in the United States as being the average requirements per head of population are $2\frac{1}{2}$ acres of agricultural crops, 3 acres of humid pasture, and 4 acres of forest. The corresponding figures for Oriental countries must be considerably less, as the standard of living is lower, but it is significant how very far short of these figures are the natural resources in grazing and forest land of almost any thickly populated country.

A sufficiency of timber is not by any means the sole consideration in maintaining land under forest, though it is in the growing of high grades of timber that the forester's scientific training finds its main justification. The other uses and advantages of forests, such as have been outlined above, should also be emphasized, particularly in countries where some form of democratic government is being developed and the average citizen is expected to make his wishes known. Under most so-called 'popular government' systems, the long view necessary for sound forestry and land-use planning is apt to be sacrificed to temporary gains, or to the force of political pressure. The forest officer is generally an employee of the government, and as such is debarred from any public action or statement connected with politics, so that the best chance of securing a sound and effective land policy is in the careful and continuous education of the electorate as a whole to appreciate its value. In this connexion it is worthy of note that the countries which are at the moment making greatest strides in organized land development—namely the United States, Italy, and Russia—are those in which 'popular government' has surrendered to, or been replaced by, autocratic control by a few men selected for their technical ability, and there is much to be said for this method of securing organized planning of a country's natural resources.

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II. GRAZING AND RANGE MANAGEMENT

Range Management as a Forest Activity.

As a rough rule it may be taken that the bulk of the world's natural grazing depends at least partly upon forest growth of some kind; in (i) the humid tropics and semi-tropics with a heavy monsoon rainfall during the warm season it is almost impossible to prevent jungle growth from usurping grassland except with the aid of fire or cultivation; in (ii) the drier natural grasslands with a Mediterranean type of climate—rainfall during the colder half of the year—the highest type of vegetation is often a grassy savannah with a very open sprinkling of thorn trees; and in (iii) arid regions of uncertain or erratic rainfall, the food of all live-stock is as much from browsing as from grazing. It is only in (iv) the temperate insular climates such as Great Britain and New Zealand that permanent grasslands form a complete cover as a more or less indestructable climatic climax. It is in (ii) above that the bulk of the world's commercial stock farming is carried on, namely the western foot-hills of North America, coastal strips in South America and South Africa, and a large belt in West and South Australia, all of which have a climate of relatively low winter rainfall and long periods of summer drought. Although classed as having a monsoon rainfall, the drier western half of India and large parts of equatorial Africa suffer so much from drought that for purposes of range management they are best dealt with along with these countries, and although it does not enter into the world's meat markets, India's vast herds of hungry live-stock are nevertheless a very serious problem in range management. (It will be noted that 'range' is here used to mean any extensive area devoted to grazing. This is a different use of the word from the usual forestry term for an administrative ranger's charge, 'a forest range'.)

The allocation of grazing range to the control of a forest service has been largely accidental, depending upon whether such service or any alternative department already existed, whether grazing lands have remained in public or private hands, and whether grazing areas merged into or adjoined true forest land. Range management has developed as a forest service activity in the United States and to a less extent in Canada, while in Australia and the other large meat-exporting countries live-stock management has been left to private enterprise. In India the government has had to pioneer many activities which in other better developed countries are dealt with by private enterprise, but range management has only been attempted where the ubiquitous village herd has been a factor in forest working plans, while the agriculture departments as a whole have been fully employed with crop and cultural problems. The village herd has therefore been 'nobody's child'.

Possibly the earliest government work on range management in the United States was that of Dr. F. V. Coville, whose report of 1898 on the serious depletion of the Cascade Mountains in Oregon (4) led to their being constituted a national reserve. In this and other Western States many years of practical experience had been gained by the forest staff in the administration of grazing on similar reserves, so that when a Range Research branch of the service was constituted in 1915 it had some basis to work on. Since then it has built up most valuable data on all questions affecting stock management for the various types of forest and range lands, and because it has, relatively speaking, had better control of

grazing than of lumbering, it has registered considerable progress in grazing management. The United States Forest Service has therefore made a much greater contribution to this branch of land management than it has to silviculture, and as its officers have with characteristic generosity placed all their experience at the author's disposal, he feels that the pooling of this experience should be of considerable value to those dealing with similar problems in other countries.

Determination of Capacity.

The main point to learn is that grazing must be *planned* and not left haphazard. The basis of any plan must be the grazing capacity of the area, that is, the number of stock of a given class, or mixture of classes, which this area will support in a thrifty condition, either for a season or throughout the year, but without deteriorating the value of the area either for grazing or for any of the other legitimate uses to which such land may be put. A number of grazing capacity studies to determine the local variations in value are necessary for each district. On this basis a certain amount of grazing is allowed, and checked and altered in each subsequent season according to any improvement or retrogression which may have taken place. These grazing capacity studies take the form of a grazing survey carried out by some one who has a working knowledge of the local flora and its palatability, poisonous plants, food and water requirements of the live-stock, and in the case of forest being included, the effect of live-stock upon the regeneration. Other points which have to be considered in fixing the capacity are the erosiveness of the soil, likelihood of rodent damage to ground cover, length of growing season, class of stock and method of handling them. Having determined the capacity and arranged for the disposal of surplus stock, the next step in range management consists of equalizing the distribution of stock over large units so that local over-grazing is prevented. It is obviously quite useless to spend time and money upon a survey of the forage on a large area if after determination of the capacity for the whole area the entire grazing incidence is allowed to fall upon favourite places, such as the neighbourhood of watering points or the forest fringe, which because of its inviting shade and succulent weed growth often suffers seriously from over-grazing, although in terms of total available area the stock appear to be well provided for. The determination of the grazing capacity is just as vital in a range plan as is the determination of the growing stock in a forest working plan, but is just as great a waste of effort if the prescription is wrongly applied.

Grazing Surveys.

To make a grazing plan requires a knowledge of the distribution, palatability, and reactions to grazing of the various forage plants. One-inch maps are usually sufficient where types are broadly distributed, but 2-inch or 4-inch are preferable where the ground is broken or the type pattern intricate. The data usually collected for a forest working plan map are required, plus fences and live-stock enclosures, watering points, and other things affecting stock, such as areas of poisonous plants. Areas closed to grazing because of water catchment or wild life preserves, or dangerous to the animals themselves, should be specially marked.

A working party should be organized in much the same way as a working plan party would be for forest work, with three or four men capable of mapping the forage types on the lines laid down and working under an officer who is capable of directing, checking, and co-ordinating their work in the field, analysing their results, and applying them in a written plan.

Type classification should be undertaken at a season when a representative growth of the chief forage plants has come up; lower elevations should thus be covered first. A rough rule to regulate the intensity of mapping is that a mapper must pass within $\frac{1}{4}$ -mile of every point in the area, by mapping 40-chain strips twice in every square mile. The U.S.F.S. standard classification of types has ten main types each designated with a colour, viz.

1. Open grassland other than meadow.
2. Meadow.
3. Weeds.
4. Sagebrush.
5. Browse.
6. Range in coniferous timber.
7. Waste areas.
8. Barren land.
9. Areas of mixed woodland.
10. Range in aspen woods.

Such grouping would of course have to be adapted in other countries to meet local needs. Sub-types are too varied to be dealt with in colours, so are shown by symbols of not more than three combinations of letters, say a capital and another letter to designate each of the three chief components in the sub-type, adding a percentage density figure for the type or sub-type as a whole. Further symbols should be noted on a separate form to show: (i) the density as a decimal of the ground cover within reach of the live-stock, (ii) the percentage that each of the component plants occupies in the whole vegetational cover, and (iii) a palatability factor for the type.

Palatability Figures.

Palatability is taken as the degree to which herbage within easy reach of live-stock is grazed when a range is fully but properly utilized. A list is prepared of the common plants for the area and each is given a percentage palatability figure to indicate the amount of this plant which is grazed in the course of the grazing season; such a list can of course only be built up gradually as a result of field observations, verified if possible by quadrat measurements in grazed areas. With this list the mapper notes down the above data and works out a palatability factor for the type, as in the following example, with an average type density of 17 per cent., actually surveyed while visiting the Jornada Experimental Range, New Mexico.

The *forage factor* is obtained by multiplying the average type palatability by the average type or sub-type density. A *forage acre* is the ideal and perfectly stocked acre completely covered with vegetation wholly valuable as forage, and the forage factor is a convenient numerical method of describing the area qualitatively in terms of forage value.

<i>Principal species.</i>				<i>Pal. per cent.</i>		<i>Cover per cent.</i>		<i>Pal. factor.</i>	
<i>Weeds:</i> nil.									
<i>Grasses:</i> <i>Bouteloua eriopoda</i>				80	×	30	=	0.240	
<i>Sporobolus flexuosus</i>				70	×	5	=	0.035	
<i>Aristida divaricata</i>				50	×	10	=	0.05	
Total Grasses:						45		0.325	0.325
<i>Shrubs:</i> <i>Yucca elata</i>									
<i>Gutierrezia juncea</i>				10	×	20	=	0.02	
<i>Prosopis glandulosa</i>				0	×	30	=	nil	
<i>Prosopis glandulosa</i>				10	×	3	=	0.003	
<i>Ephedra trifurca</i>				0	×	2	=	nil	
Total Shrubs:						55		0.023	0.023
Total average type palatability 0.348									

Average type density $0.17 \times$ Average type palatability $0.348 =$ Forage factor 0.059.

The figure usually taken for purposes of calculation of the number of animals is 0.8 forage acre to support a cow, and her calf until weaned, for 1 month. To determine the number of real acres required to do this, the figure 0.8 is divided by the forage factor—in the example above, 13 acres per month or 156 acres a year.

Where detailed figures of the relative palatability of species have not yet been worked out, or where such elaborate mapping as the above system of types and sub-types cannot be undertaken, a more extensive survey to show merely grass, weeds, and browse, with one average palatability figure for each of them, would serve the purpose until more accurate figures are available, and could probably be incorporated as part of the normal revision of forest working plans extended to include neighbouring grazing lands under government control.

Botanical Studies.

Having assessed the range resources, the next step is to find just how closely the forage plants may be grazed without impairing their growth and future productivity. It will usually be found that out of a comparatively long list of local forage plants in natural rough pasture lands, only a very few species are of real importance. For instance in the Northern Great Plains Station at Mandan, North Dakota, out of nearly 300 species of plant, of which over 50 are grasses in an open bunch-grass type covering barely half the ground even at its most luxuriant stage, only some 25 plants are of real importance from the standpoint of grazing. Out of these, two grasses, blue grama (*Bouteloua gracilis*) and western needle grass (*Stipa comata*), produce nearly half the forage. From this one might suppose that calculations and lists such as the Jornada example are unnecessarily elaborate. On the other hand, an accurate knowledge of the flora and its utilization by the live-stock is essential if poisonous plants, often obscure and sporadic, are to be traced, and guidance obtained from the ecological indications of progress or retrogression. A common feature of most grasslands is their capacity for standing up to great punishment for a long time without apparently showing any ill effect to the casual observer, then collapsing suddenly and surrendering completely to a poorer ecological type or to widespread sheet erosion. Such disasters can as a rule be foreseen by any one with a detailed knowledge of the local flora and its reactions.

At this North Dakota Station an interesting set of *mapped quadrats* had been kept under observation for several years under different intensities of grazing (6). A square metre is marked with pegs and the vegetation on it charted once a year on to graph paper, using a pantograph which, by tracing the actual vegetation outlines on the ground, gives a reduction to one-fifth of the original. A comparison of a series of years gives the detailed history of the patch, and shows in this case that the needle grass had been very seriously reduced by heavy grazing. *List quadrats* are merely lists recording plants by species and number which occur on a given permanently marked line; the lists in this case showed clearly that in a few years *Artemisia frigida* had increased under heavy grazing until it was two to three times as thick as in any of the more lightly grazed pastures. *Clipped quadrats* are small permanently marked squares cut close to the ground with a pair of shears in order to get data of the period of active growth, the effects of frequency of removal, and total quantity of forage produced. They must of course be closed to grazing. At Mandan these showed that the period of most active growth is in May and June, when the cattle make their most active gain in weight. In the south-west clipping to a height of 2 inches above the ground gives good results in 16 to 20 inches of rainfall, but in drier areas this is too low and the health of the pasture suffers (9), so more must be left.

Isolation transects are fenced strips in which one unit 20 feet square is closed to grazing each year, a middle strip remains permanently closed, and a third row of previously closed units is opened (Fig. 1). These form an historical and cumulative record of the effects of grazing. The transect in the heavily grazed pasture shows most *Artemisia frigida* in the units which have been open to grazing longest; this plant has therefore been adopted as the most reliable local criterion for over-grazing.

opened in:	A	B	C	closed in:
1928		Perman- ently closed		1928
1929				1929
1930				1930
1931				1931

FIG. 1.

Similar pasture experiments have been established in Australia, New Zealand, and Great Britain (7 and 8) for the detailed study of grasslands, and those interested are advised to obtain the *Herbage Bulletin Series* for more detailed information. In the New Zealand work the *point quadrat* method has been developed by taking a large number of points at random. All vegetation is recorded that is hit with 1 of a row of 10 hatpins each 2 inches apart which can be pulled up and down through a wooden frame. The number of pins is immaterial provided a sufficient number of points is taken, say 100 to obtain the dominants in a pasture, 400–500 where the lesser constituents are required. This is described as the Cockayne-Levy method. Where the pasture consists of

browse bushes or large plants, some type of quadrat frame standing higher from the ground is needed. For this a metre square frame set up on table legs, giving 100 registrations with a sliding wooden rod containing 10 long wooden or steel pins, is described in (7). The American practice for high vegetation is to use leg extensions for the pantograph.

The grassland workers at the Waite Institute in South Australia (8) combine random sampling, by throwing a 2×2 link frame 10 times in one plot or pasture, with the weighing of the different constituent species in samples cut from these squares. These together give the *percentage productivity*, but further data are of course obtained to give the value in terms of palatability. All recent work emphasizes the very great use of field notes fully illustrated by photographs.

Range study plots are random fenced enclosures put down in the middle of open range and are most valuable in giving an indication of the amount and speed of recovery of the natural regeneration when it is given protection from live-stock. Such plots are apt to give disappointing results when the damage done by rodents is not fully appreciated. It is advisable, therefore, to have part of each such plot fenced against rodents as well as against live-stock.

Live-stock Studies.

The usual method of finding the stock-carrying capacity of a pasture type is to divide a uniform field into a series of fenced areas which are subjected to various intensities of grazing. The common difficulty is to provide water, and this can best be done by arranging the fencing like the spokes of a wheel, radiating outwards from a natural water supply, or from a tank to which water is pumped by a windmill or small motor. Good examples of this were seen at Mandan, North Dakota, and at Fort Keogh, in eastern Montana, where the Northern Rocky Mountain Forest Experiment Station co-operates with agricultural agencies in stock-raising experiments. Both are in the natural prairie type of a sparse and very incomplete ground cover of bunch-grass and sage brush (*Artemisia* species).

In the Mandan work four pastures are operated under continuous grazing during the 5-month season at the rate of 1 two-year old Hereford steer to 10, 7, 5, and 3 acres, but in order to simplify the weighing of the live-stock the animal number is kept constant and the size of pasture varies. A fifth pasture is worked on a rotation which is described in detail below, giving an incidence of about $4\frac{1}{2}$ acres per head. These have been in operation since 1917 and are still maintained, and the results, combined with botanical studies described above, give a most illuminating picture. Conclusions may be summarized thus: After the unusually prolonged drought of 1933–4 only the 10-acre pasture survived the whole of 1934 season, the cattle on all the others having to get supplemental feeding. Over a normal series of years, however, the 10-acre allotment is larger than necessary, and unpalatable *Artemisias* other than *Artemisia frigida*, and composites tend to increase through under-grazing. The 7-acre allotment gives the best weight gains, but the pasture is not so completely utilized as in the rotation pasture. The 5-acre allotment is not large enough, as cattle do not maintain their gain in weight in the latter part of the season, and *Artemisia frigida* has increased. The 3-acre allotment is severely over-grazed, and even in good years supplementary feed has had to be given before the end of the 5-month

season; the native vegetation has been seriously weakened and *Artemisia frigida* has increased many-fold in abundance and in the virility of the individual plant.

Deferred Rotation.

In the rotational pasture the weight gains have not been quite so high as the best gains made, but a high utilization of the pasture has been obtained without injury to the vegetation. This method of rotation has as its base the very sound idea of allowing each division to mature a grass crop for two successive years before it is harvested by the cattle, so that each division in turn will have a chance to produce a normal seed-crop and the resultant crop of seedlings. This can best be shown diagrammatically:

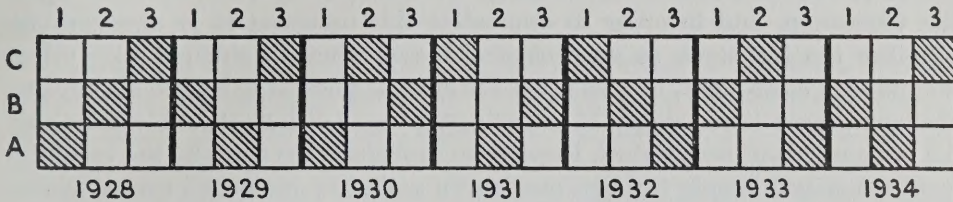


FIG. 2.

(1, 2, and 3 indicate spring, summer, and autumn.)

Thus C, which is given the first chance of regeneration, is grazed last in 1928 and 1929 and second in 1930, by which time the seedling crop of the two previous years should be well established. In 1930 and 1931 B is grazed last, and in 1932 second, after which A is given its chance to regenerate.

Combined Grazing and Cutting Studies.

The above example of single field trial is open to objection on the ground that large errors may occur owing to the variation in the pasture itself within the area chosen, and to variations in the stock themselves. New Zealand workers have therefore developed an interesting substitute in their handling of sheep with a method of 'replicated fields plus an auxiliary area' (7) in which a permanent flock is rotated in short grazing periods of a few days through a four-field rotation, an auxiliary pasture and extra sheep being used to balance any unequal developments during the season. This is probably too elaborate a system for ordinary local grazing-capacity measurements but is well worth study by any one undertaking such measurements, as it indicates the common errors and limitations of single field trials.

A more practicable modification is to *combine the clipped quadrat and grazing*, and this is the method which holds out most hope for evolving a simple and reliable measurement with a minimum of expense. The effect of mowing or cutting is not comparable with grazing, as the soil is robbed of the manure which grazing animals drop on it; flat plants such as white clover also prosper at the expense of taller herbage in a way not comparable with grazing. Clippings, on the other hand, give a more easily measurable product than does the periodic weighing of many animals. A method of alternate clipping and grazing has been evolved in New Zealand (7). The size of plots is limited to what a team of men can cut and weigh in a day, remembering that morning dew often delays the start. An ordinary lawn-mower can be adapted by replacing the usual wooden

roller with two small side wheels and providing an efficient catcher for the flying clippings. Where browse and bushes are important, clipping by hand would have to be relied on. The period between cuttings and grazings varies with the rapidity of growth, anything from 10 days to 2 or 3 months. From 20 to 40 sheep are used for each grazing, giving a stocking rate of 80 to 160 to the acre, and are kept on the plots just long enough to ensure full utilization of the herbage. The mower and weighments constitute the measuring agents, the sheep the managing agents, in this type of experiment.

Pasture Deterioration.

The manner in which stock use range land has an important influence upon the vegetation, and in order to appreciate this influence it is necessary to visualize the live-stock as an ecological factor which, combined with other factors such as drought, may so upset the local balance as to lead to a complete change in vegetational stage. It is wrong, not to say dishonest, to blame nature for bringing about heavy stock losses from drought when actually the calamity has been staged largely through man's own action by prolonged over-stocking of the range. Most humid grasslands are intermediate ecological stages towards some more luxurious plant type, thus under-stocking of pasture leads to its transition into scrub in parts of New Zealand, and in Great Britain into a weedy condition. Even in many arid vegetational types the natural succession is towards a tree or bush climax, and even where true grasslands do form the highest type for the given conditions, the balance is so delicately adjusted that a very slight climatic change or increased biotic influence, be it live-stock, rabbits, fires, or smelter fumes, may upset it and ruin its grazing value by replacing it with inedible scrub or nothing at all. Again, even on pastures under organized control, species which are particularly luscious bites may be so constantly nibbled that they may disappear entirely from the locality, although the general character and composition of the cover has not otherwise varied.

The efficient pasture plant must be able to recover after grazing and to maintain as high a rate of recovery as possible after each successive grazing (10), and these are the features which are aimed at in improvement by breeding special strains of pasture plants. Unfortunately in the management of wild range lands the forage plants may not be at all efficient in this sense, although they provide excellent food at certain times of the year. Any plant, no matter how virile, will succumb sooner or later to prolonged continuous heavy grazing, browsing, or lopping, and it is only on some basis of periodic resting at its most vulnerable stage that a depleted area can be nursed back into full productivity. The chief causes of deterioration in range lands are:

- (i) Premature grazing when vegetative growth is just beginning in the spring or the break of summer rains.
- (ii) Continuous grazing without any respite.
- (iii) Over-grazing by trying to feed too many animals off too few acres.
- (iv) Trampling and puddling the soil when it is soaked.
- (v) Using the wrong kind of stock or the wrong mixture of classes.
- (vi) Bad distribution through concentration of stock at watering points, night bedding grounds, freshly burnt areas, or on succulent forest fringe.

'Over-grazing' has come to be used as a general term for all these forms of abuse, though in a great many cases proper control on a scientific basis will provide for a larger head of stock, and certainly a larger eventual revenue, than can be got from land where any one of these faults is found, or where indiscriminate burning is allowed. Premature grazing has undoubtedly been one of the main causes in the deterioration of the Western States ranges, and the present astonishing difference between Forest Service range and uncontrolled 'public domain' is due quite as largely to the fixing of annual grazing periods as to the reduction in the number of live-stock. Unappropriated public domain suffers from common competitive grazing almost as seriously as common village waste lands in India.

Examples of Deterioration.

According to census reports the live-stock population of the eleven Western States grew between 1870 and 1890 to 11 million cattle and horses and 15 million sheep, and many of the ranges were even at that date becoming over-grazed. Subsequent prolonged droughts and low prices caused further overstocking, and in the early 'nineties thousands of animals died from starvation. Since then the development of irrigated pasture and supplementary feeds has more or less balanced the general decline in range capacity, so that the total number of animals in these Western States was approximately the same in 1930 as in 1900. Prolonged drought and low prices since 1930 have repeated the experience of the 'nineties, and by 1934 most of the public domain and private range was carrying two or three times more stock than it could be expected to support. This very critical situation was only alleviated in the autumn of 1934 by the Federal Government purchasing over 6 million head of cattle, nearly 1 million of which were so starved that they had to be killed off at the ranches. Accurate field comparisons between average range land and ungrazed areas such as cemeteries and railway enclosures show how widespread and serious this depletion has been. Cows become so poor that milk yield and calf crops are reduced and the calves are stunted, while sheep suffer in the same way, both mutton and wool production degenerating. Where flocks are communally owned or each small farm has its own herd, the decreased returns affect the whole of the rural population, whether they are actually dependent upon a meat export trade or not.

In central Utah good stands of perennial grass in the glades of the aspen and alpine forest types used to support cattle at the rate of less than 2 acres per month, but over-grazing has reduced them to poor annual grasses and weeds, of which at least 10 acres are needed per cow-month, and the existing cover is inadequate to protect the topsoil, which is being eroded away. In western Montana grassland has been degraded to a mass of composite weeds such as *Chrysothamnus* and *Aplopappus*, the capacity having fallen from 2 acres to 11 acres per cow-month. On the Edwards Plateau in south-western Texas, where large herds of mixed cattle, sheep, and Angora goats are run together on oak browse and grass, the poisonous bitterweed *Actinea odorata* has increased as a result of heavy and continuous herding, and has caused heavy losses amongst the stock, which will not normally touch it if well fed. In southern New Mexico the valuable black grama grass (*Bouteloua eriopoda*) is easily

replaced by a worthless composite *Gutierrezia* and subsequently by wind-borne sand dunes piling up around isolated bushes of mesquite (*Prosopis glandulosa*).

Such examples could be multiplied indefinitely from any other more or less dry and heavily grazed country, but two imperial examples will serve to show how widespread this problem is. In the Central Provinces of India the best fodder grasses are annual and are commonest on the forest fringe, but constant heavy grazing tends to replace them with coarser perennial grasses and weeds such as *Cassia tora*; it also prevents the forest species from establishing themselves, so both as forest and as grazing ground this fringe is deteriorating and retreating. In the central pastoral region of Northern Rhodesia excessive stocking leads to a change in type from the tall grass phase of ungrazed grassland (*Hyparrhenia*, &c.) to a pasture phase with the tall grasses being trodden out and replaced by creeping perennial grasses, such as *Digitaria setivalva*, often very palatable. This in turn gives way to worthless free-seeding grasses which only persist for a time and eventually give way to a waste of weeds (11).

Classes of stock.

The suitability of the various classes of animal, viz. beef cattle, dairy cattle, dairy buffaloes, sheep for mutton or wool, milk goats, Angora goats for mohair, camels, horses, pigs, &c., depends upon the type of forage and terrain available, and upon the local requirements and market limitations. Often the existing class kept by natives is not by any means the most suitable to the country or their real needs.

Cattle and horses use grass range to better advantage than sheep, as they use the coarser drier grass rather than eat weeds or browse plants, though a larger number of browse plants appear to be palatable to sheep than to cattle. Goats are primarily browsers; when grazing is good they will eat green grass and succulent weeds; when times are bad they are practically omnivorous and are excellent tree climbers when really hungry; it is astonishing how completely hungry goats will strip a country-side. Sheep and goats can go for several days without drinking provided they can get some succulent or dew-soaked herbage; cattle, on the other hand, need water at least every 2 days (12). The daily travel of goats is greater than sheep and cattle; according to some interesting data collected at Sonora in the Texas plateau (13) the maximum distance travelled by a goat is nearly 12 miles a day and the minimum just over 2 miles, the corresponding figures for cattle and sheep being a maximum of $6\frac{1}{2}$ miles and minima of 1 and $1\frac{1}{2}$ miles, and the average being: cattle 3 miles; sheep 4 miles; goats 6 miles.

If a range can be fully and properly utilized by one class of stock, there is no point in grazing two classes in common unless they are definitely required for some economic purpose. There are, however, many instances where both the animals and the pasture thrive with a mixture of stock. In heavy growth, cattle will trample down forage which sheep could otherwise not reach, and a few goats serve to keep brush browsed back to the advantage of the herbage. In English pastures the alternation of cattle and sheep is becoming recognized as an efficient method of controlling certain weeds. As a rule, however, the mixture of classes complicates attempts to assess the capacity of the range. In American practice the relative weight of the average animals is used as a basis

for allotting them a share in a range plan—e.g. in Texas they use the ratio of 1 cow to 7 sheep and 8 goats; in the absence of more accurate figures this is a useful figure to have, but we doubt if it accurately represents the real ratio of destructiveness. A range as a whole may be best suited to the animals already using it, and yet afford far better utilization if different classes were segregated and grazed according to their individual requirements under a scheme of fencing and separation of stock classes.

Reduction of Surplus Live-stock.

In several African colonies and in India the people keep large herds of stock although the basic reason for commercial stock-raising, namely a meat market, is absent. Their reasons for keeping live-stock, surplus to their own milk and meat requirements and their plough oxen, are often obscure and are mixed up with the primitive idea that a man's wealth is judged by the number of animals, wives, and children he has accumulated. Live-stock may have a very high value in meeting marriage dues and dowry obligations, although no actual sale of stock is carried out. Possibly the best justification for the Indian village herd is that it constitutes the only source of manure for the fields, and this is certainly a point which requires very careful thought in framing any attempt to reduce the surplus herds to reasonable proportions. In the absence of forests, cow-dung also forms the only fuel supply.

In countries where the natives have no religious scruples against killing off surplus animals the matter is probably largely one of how much the government can afford to pay as compensation for animals surrendered; if no other use can be made of the carcasses, it might possibly be worth considering reducing them to some form of fertilizer. With a Hindu population, however, any action of this sort would be strongly resented, and in such cases the following are suggested as lines of action which will gradually bring about a sounder rural economy:

1. Establish demonstration farms and fenced plots which will give practical illustrations of the benefits of lighter grazing.
2. Educate the rural population in the simpler essentials of animal husbandry.
3. Introduce the use of bloodless castration, in which the local range guards can easily be trained, and the separate herding of bulls, rams, and goat bucks.
4. Produce a cheap nitrate fertilizer for use on ploughed fields, or bone meal for feeding to animals, wherever cheap water power makes the establishment of chemical factories feasible.
5. Create village fuel plantations to provide a substitute for cow-dung as fuel.
6. Encourage the use of green manure crops (ploughing down leguminous and other herbaceous crops to increase the organic content of the soil in cultivation).
7. Develop the use of a compost manure in which all vegetable and organic waste matter is made use of. This produces a much larger volume of manure than is obtained by merely saving up the excrement of the animals. The only cost entailed is manual labour.
8. Develop the use of the silage pit to produce cheap supplementary feed when grazing is poor. All other manufactured feed is much too dear to

be a feasible proposition, but by saving all available green crops, ensilage is a valuable and cheap feed.

9. Stop common grazing by dividing up the village common land into plots allotted to families or groups, so that some individual responsibility may be created in checking over-grazing. The limiting factor for such a scheme is almost invariably the water supply, which can seldom be distributed through a series of small paddocks.
10. Where grazing rights are practised to the detriment of the pasture, or of a larger community, as in the over-grazing of a water catchment or other public interest, legal action should be instigated to have the rights modified or cancelled. A right ceases to be legally valid where it is practised to the detriment of the owner, i.e. government as representing the public. Where rights cannot be modified legally, it might be feasible to have a conservative grazing incidence fixed by assessors, and introduce a tax on animals surplus to such an assessment.

Distribution, Fencing, and Salting.

Stock will always tend to congregate in the immediate neighbourhood of water and of natural salt-licks, or at salt troughs where these have been supplied to them. Where cattle are always admitted to a reserve through one gate, or where the village herd returns home daily by the same route, a concentration of heavy grazing always occurs along these much used approaches. Having reduced the herd to the numbers indicated by a grazing survey, it is essential to prevent local concentrations of this sort and distribute the incidence over the entire area as evenly as possible. In the case of village herds it is hard to break the habit of bringing the entire herd home to bed down in the village corral each night; the need for milking and for collecting all possible droppings, and the fear of predatory leopards, makes corralling essential. It should, however, be possible to persuade the villagers to have the dry animals separated from the milkers and corralled in some other place from which the manure could subsequently be carted to the fields; this would serve to distribute the grazing somewhat.

To secure the maximum utilization of the range, some form of deferred and rotational scheme such as has been outlined above should be employed. This will usually entail some form of fencing unless there is considerable variation in elevation within the range which thus falls automatically into a series of seasonal climatic zones which need no artificial separation. Use should be made of all natural boundaries such as watersheds and streams to reduce fencing to the minimum. On the other hand, good distribution of stock is easier to maintain on small units than on large ones.

The feeding of salt, and if possible other minerals in which the feed is deficient, should be part of the regular routine for all stock. This is essential for their proper health and also serves a useful purpose in adjusting the grazing incidence when properly placed out in the range. For cattle the amount varies considerably according to the amount of natural salt in their feed and water, and the presence of natural salt-licks on the range; cattle need more salt on a browse diet than when eating grass and weeds (14); the actual consumption varies from 1 to 2½ lb. per head per month, averaging 20 lb. a year. For sheep 3 to 4 lb.

per head per annum is quoted, but it should be fed to them little and often, say every third day, rather than issue larger rations less often. Commercially prepared blocks of evaporated salt are recommended, but doubtless the rock-salt commonly sold in eastern bazaars will serve, just as it does for army mules.

The salt should be placed far out on that part of the range to which it is desirable the animals should be attracted; where water is abundant and well distributed the placing of the salt presents no difficulties, but where the topography is rough and watering places are few the amounts of salt placed must correspond roughly with the amount of feed available in each place. To make sure that the animals know the location of the salt dumps it is only necessary to have some of them driven past each of them once. Salting should *not* be done at the watering points as this tends to keep the animals hanging round, thereby increasing local over-grazing and losing an opportunity of utilizing much of the outlying feed areas. Much can also be done in this direction by creating temporary watering points by digging large shallow pits where casual water will collect and lie for some little time after storms; these temporary water supplies will allow cattle to work out to pasture and salt deposits which they could not normally make use of. Where village cattle are led out each day by small boys, the day's salt ration should be carried out and placed suitably with reference to the areas in which the animals are expected to work through that day.

Water.

An adequate supply of good water is as essential to live-stock as is forage. The shorter the distance between watering points the better, and every opportunity should be made for developing and improving the supply by building up a reserve in tanks or pits. The windmill pump now used almost universally in the States is cheap and fairly simple to install; this would be a very sound investment for any community whose usual supply is a seasonal stream which is liable to dry up in the dry season. Approaches to drinking troughs should be kept dry, and stone packing should be put down along the boggy edge of natural ponds, because weak animals are liable to get bogged in soft mud. Springs and seeps which flow into puddles can be made to serve better by trapping them into troughs.

In the typical foot-hills grazing ground the pools in the main streams gradually dry up as the dry season advances, so that the hotter the weather and the weaker the stock from scarcity of fodder, the farther they have to go in search of water. This can be reduced to some extent by building a series of low walls or check-dams across the stream-bed which will increase the permanence and number of reliable pools. In sandy river-beds coffer-dams may serve to tap underground water. The range plan should if possible include the provision of a nucleus of permanent water supply which can be relied upon absolutely should the surface streams fail through prolonged drought. This generally means deep wells, or piping water from some distance, all of which entails capital expenditure.

On plains and rolling country watering points should not be more than 5 miles apart; for hilly country 3 miles. It is very obvious in the ranges of Arizona and New Mexico, even on well managed ranches, how seriously the vegetation suffers from watering-point concentration of stock; in some cases

it is killed out entirely for nearly a mile in every direction around a permanent watering point. Obviously such treatment must seriously affect the carrying capacity of the range as a whole, and can best be alleviated by working up more seasonal and temporary watering points in the parts farthest from these permanent points. This is particularly necessary when rains are erratic and in localized showers, because fresh growth in certain areas cannot be taken advantage of unless water is also obtainable there. Earth tanks with a puddled mud surface are preferable to and cheaper than concrete work for such temporary tanks.

Live-stock Associations.

Whether the grazing range is privately or communally owned, or is government range used on lease or permit, some committee or association of stock owners should be encouraged and given official recognition, because an organized body having a common interest in range practice makes co-operative action possible and is the obvious channel through which any improvement in range management can be presented to the local population. A good example of this type of organization is seen in British Columbia, where large areas of provincial government range land are grazed on lease and on permit (15). Live-stock associations are purely advisory and not administrative, except in so far as definite tasks, such as fee collection and fire control, are delegated to them. The whole of the grazing land is divided into grazing districts, in each of which an association is recognized. These bodies have to comply with the law of the country as regards registration under company law in order to do business, but their main use is in providing a means of joint discussions and obtaining a majority view-point on improvement and investments. The official declaration of the organization should specify 'the protection, management, and improvement' of the crown or other land in use. The membership must include a majority of range users for the district or unit covered, and care should be taken to have this verified before official status is given. Recommendations of a vital character should require a very definite majority in order to obtain real co-operation, and in cases where a few larger owners are liable to be outvoted by a majority of smaller men, some weightage system may have to be introduced on the basis of revenue, acreage, or number of animals held. Problems of local interest usually discussed are: arrangements for handling stock to comply with the range plan; breeding and joint ownership of bulls; assessment of range capacity and action to reduce local over-grazing; water development; fencing and salting technique; assessment and collection of fees. The chief means of contact is between the local forest officer and the committee of the association, but it is essential to have it made clear that the association is advisory rather than executive, and that final decisions must rest in official hands where government land is concerned.

This type of association is well developed in the Kamloops district of British Columbia, where government range carries over 600 permits covering nearly 90,000 head of cattle, horses, and sheep. The district forester, Mr. G. P. Melrose, has been active in its encouragement. Some associations are more active than others, depending upon the urgency of their problems and the aggressiveness of the community leaders; the more active ones are preferable, as their

troubles are made known and can be met, whereas in the less active communities difficulties remain unsettled.

Control by Lease or Permit.

The alternatives usually employed for controlling the use of government range land not burdened with grazing rights are by lease or permit. A *lease* is usually given to one individual or association for a number of years on an annual rental based on the approximate range capacity; such a lease allows complete control of the land for range purposes, but should provide stringent penalties against over-grazing or other misuse. *Permits* are generally on a monthly or seasonal basis, but with no security of tenure beyond the short period they cover; they are issued per head of stock up to the calculated capacity of the range, and are generally distributed amongst a number of stock owners all using the same range; it thus amounts to common range use, except that local residents are given priority and immediate closure can be enforced if any abuse arises. One or other of these systems may be locally popular, but difficulties and abuses which are often blamed on the system are more probably due to the outlook of the users or the failure of the owner to cope with the abuse. The system of leasing should in theory give the sole user scope for a long-term investment in fencing and range improvement, and an incentive to proper use which is lacking in the permit method.

Breeding and Improvement of Stock.

Where stock is being reared for a definite market for meat, namely beef or veal, mutton or lamb, goats' flesh, pork, there is a clear incentive to produce the maximum weight of meat and number of young animals. Where the market is for dairy produce, wool, hides, or mohair, the aim of breeding is not so clear-cut, and some other basis than weight gains may have to be adopted as a measure of pasture efficiency. In all cases, however, the effect of under-nourishment is to reduce the commercial returns; poor and emaciated stock are notoriously bad milkers, and are liable to many diseases and pests from which fit animals are exempt.

The question of the breeding of stock is a very large one which cannot be gone into fully here. It is very desirable that the possibilities for improvement of local stock should be explored. Uncontrolled breeding by poor bulls and rams must be stopped and advantage taken of the facilities which most governments have now provided for the hire or borrowing of stud animals. It is, however, essential to recognize that improvement in the type of stock, unaccompanied by proper feeding, is worse than useless. Scrub cattle and sheep have been bred by a long process of time to be more or less immune to diseases which will kill off half-bred stock which have to compete with the scrub animals for a limited food supply. This has been a fairly common experience in several parts of India and Africa, where enterprising agricultural officers have tried to improve the local breeds without first ensuring better nutrition.

Uncontrolled breeding has previously been a serious problem in countries where the religious scruples of the people are against bloodshed or interference with the natural increase of the herds. There are now available on the market or on loan from agriculture departments various forms of bloodless castrator

such as the 'Burdizzo' patented by Dr. N. Burdizzo of Turin, Italy. The operation causes little pain or discomfort to the animal and is a definite improvement on the use of a knife, as it avoids the danger inseparable from an open wound, and has been proved to give better subsequent weight increase in various tests.

Pasture and Ration Improvement.

Under the more intensive methods of production there are several alternative ways of improving the available forage supply and supplementing it with other foods which will ensure that the stock receive a balanced ration. These may be classified thus:

- (i) Improvement of existing pasture by top-dressing with mineral salts in which it is deficient, and sowing to improve the natural stand of grass.
- (ii) Supplementing forage with other foods such as concentrates, mown hay, silage, and 'licks' of minerals in which pasture is deficient.
- (iii) Cultivation of artificial pastures sown with special grass species.

Each of these problems has been dealt with in most countries and an extensive literature written by agricultural specialists exists. It is not therefore proposed to deal with them further than to say that, wherever the live-stock trade pays sufficiently well to justify it, any one or a combination of these should certainly be undertaken.

Under the extensive grazing of wild lands, where small returns do not justify any large expenditure in trying to improve the range, the question is a more difficult one. Sir J. B. Orr has given an excellent summary of pasture deficiencies in various countries (16), which brings out clearly how very seriously pasture lands almost all over the world are deficient in mineral salts. He shows that these deficiencies are the chief cause of disease amongst live-stock, but has omitted to mention erosion as a factor in creating these deficiencies. Many range lands once well provided with mineral content have been robbed of this through a long process of exporting the bones, meat, and hides which they served to build up; others are naturally deficient through geological or climatic peculiarities; but practically all are suffering to a greater or less extent from the erosion of the top-soil, in the loss of which the available chemical content is far higher than the actual physical removal of soil particles. Malnutrition due to mineral deficiency is likeliest in old countries on uncultivated grazings and in new countries where the native stock has been improved in grade without improvement in pasture. Recent work in South Africa, Kenya, Rhodesia, and Australia all shows that the composition of the soil, the composition of the pasture, and the health of the grazing animal are intimately connected, and that many ailments and epidemics are due to lack of phosphorus, no matter what local name the disease has been given—e.g. 'stysiekte' in South Africa, 'coastal disease' and 'dry bible' in Australia, 'creeps' in Texas, 'brittle bone' in Europe. For India, Orr notes that the effects of any particular mineral deficiency are overshadowed by the effects of sheer starvation, but presumes that the deficiency of phosphorus is serious from the fact that in 5 years, 1920-5, over 520,000 tons of bones were exported without any compensatory return to the soil.

In undertaking any work for the improvement of stock using wild range land,

therefore, it is essential to realize that it is not sufficient to increase the vegetative yield of forage and reduce the herd to reasonable proportions, though of course these are important. Some provision must also be made to meet this mineral deficiency where it is a dominant factor. This can be done in two ways, either by spreading a top-dressing on the pasture, or by feeding 'licks' of mineral salts or bone meal to the animals themselves; in extensive range management the latter is obviously the more suitable.

Recent work in Australia indicates that an available phosphorus content is produced by *Trifolium subterraneum*, the underground clover, after a short period of years, thus building up a new fertility wherever this clover can be grown. The intensive cultivation of pasture, chiefly by encouraging a heavier percentage of clover by top-dressing pastures with some nitrogenous fertilizer, is a familiar feature of farming practice, but has always been considered too expensive for extensive range lands. If, as is now reported, a phosphorus deficiency can be met from a clover crop grown on phosphorus-lacking soils, it becomes more than ever essential that we should master a technique for growing it on range lands. Imperial research workers now regard clover as fundamental to any large-scale grassland improvement.

A method which gives good results is shallow harrowing with a wooden A-frame harrow and sowing suitable grass seed (19). The grass seed may be harvested locally, but as a rule it is cheaper to buy some reliable market supply of a strain which is known to be locally hardy. Some perennial which will persist for several years is best, though permanent pasture can also be produced by a quick-growing annual which is capable of profuse reproduction from seed which lies dormant through the period of extreme drought each year (17). Possibilities of using introduced foreign grasses should be explored, and sample sowings made in any convenient forest nursery. Excellent results have been obtained in Canada and the north-western United States with the Russian crested wheat grass (*Agropyron cristatum*) which gives a very profuse seed crop and is hardy to intense cold and drought (18). A limited supply of seed is obtainable from the Dominion Agrostologist, Ottawa, who reports that although this grass is a cool climate crop and produces a vigorous crop during the cool season only, it can persist dormant through summer temperatures and long droughts. For hot dry climates the *dhub* grass of India (*Cynodon dactylon*), known in most countries as Bermuda grass, and the blue grama of the South-west (*Bouteloua gracilis*) have given good results in New Mexico (20). Where grass is poor and the bulk of forage is of browse plants, the possibilities should be borne in mind of finding fresh species which can be cultivated by sowings on roughly harrowed ground to augment the local list of browse species; such for instance as winter fat (*Eurotia lanata*) which is an excellent stock feed, and the four-wing salt bush (*Atriplex canescens*), whose seeds and leaves are devoured readily and have good fattening qualities; seed of both could be obtained from the Director, State College, New Mexico, or the Director, South-western Forest Experiment Station, Tucson, Arizona; and the Australian salt bush (*Atriplex semibaccata*) which has succeeded as a forage plant in the drier districts of California. Subterranean clover (*Trifolium subterraneum*) is having a great vogue with Australian sheep men and should be well worth a trial in any areas which have a definite winter rainy season. The preparation of the soil of grass-

lands by harrowing for such sowings serves not only to help the seed, but it also counteracts the consolidation of the soil through puddling when it is wet, and it distributes the droppings, making for some improvement in these ways.

Alternative Sources of Food.

The making of silage as an additional source of food when pasturage is not available should be far more widely employed than it is. The pit should be dug with vertical sides and sloping ends, so that the carts bringing in the green matter can be driven into it to unload, consolidating the whole lot as they do so. As a rule planted crops such as maize and sorghum are used for silage, but excellent results can be obtained by using any of the coarser grasses, cutting them before they reach the flowering stage; good pit silage was made by the Military Grass Farm at Dehra Dun in the United Provinces, with Johnston grass (*Sorghum halepense*) which is a troublesome weed there and in many irrigated areas in both the eastern and western hemispheres. Silage is not in itself a balanced ration and it usually requires some hay to make it complete.

The use of cultivated grain crops for fodder or silage is usually out of the question on the score of expense, but there are wild grains and seed-crops which are worth developing. During the last few years West Australian sheep men have been making increasing use of lupin for a summer grain feed, as it yields a good crop of edible seed (17). Shortage of ordinary forage on the south-western desert ranges and in Texas is frequently met by preparing cacti and other spiny plants which the stock cannot eat in their ordinary growth form. The practice is to singe off the spines with a paraffin blow-lamp fitted with a 3-foot pipe; another method of preparation is to fell the plants and pass them through a crusher, the pulpy mass being sufficiently wet to swell and soften the spines. The spiny yucca can also be made into fodder by felling and splitting the stems after the spiny leaves have been burnt away, and the fibrous but pulpy stems are fed either raw or as ensilage. The food values of cotton seed and of cereal straw are well known to most stock owners, but their value is often lost because it is only when the animals are at the extreme stages of starvation that they receive such rations.

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III. OVER-GRAZING AS A PRIMARY CAUSE OF SOIL EROSION

Normal or Geologic Erosion.

WHEN dealing with the problems of land use, it is necessary to understand the basic processes of soil building. Soils are built up through very long periods of time by the denudation of previous land surfaces, and the combined action which subsequent climatic changes and plant life bring about. The normal processes of erosion are thus an inevitable part of all soil building, for the slow wearing down of all land surfaces serves to build up fresh ones. The height of the land, and the geological age and composition of the formation, all have their effect in the development of a slope profile, and also of a soil profile, characteristic of any given area. Thus in the geological history of a typical block of mountains: (i) a debris fan appears at the foot of each rounded fold in the hills; (ii) later these folds grow to gorges and the slopes show triangular facets; (iii) later still as the range wears down, the triangular facets disappear and are replaced by longer parallel spurs, while the detritus-filled gorge mouth has developed into a wide triangular plain; (iv) later still the parallel spurs are subdivided by tributary gorges, and the foot of each main spur forms a toe running out into the debris plain; (v) the last stage towards the final peneplain is when the detrital plain envelops the remains of the ridges, which are left as islands in its level surface (21).

Throughout these various stages the amount of soil and vegetation is decided much more by the climate and precipitation than by the geological stage. Given the same geological basis of similar slope and dip, three definite types of *slope profile* can be outlined empirically:

- (a) Under arid conditions of less than 20 inches rainfall, there is very little soil building through the accumulation of vegetable matter in the sense in which it occurs in more humid regions. The streams flow spasmodically from the more or less bare surfaces, but being unable to carry away all the detritus they have collected, they deposit it in wide sandy washes

below. The typical slope profile for arid regions is therefore concave upwards (Fig. 3).

- (b) Between arid and humid conditions there is an intermediate picture where removal occurs about as rapidly as weathering provides fresh material, and the slope profile develops as a straight line set at approximately the angle of repose of the fragmented material.
- (c) In humid conditions, on the other hand, the accumulation of partially rotted rock, and the accumulating vegetative cover above this, produce between them a spongy stable cover over long slopes, at the bottom of which the accumulated stream-flow from large areas tends to undercut and reduce the soil accumulation. The slope profile for humid regions is thus convex upwards (22).

These processes, however, are all exceedingly slow, and even while they are in progress need not be considered as an active factor in a plant's environment, for the time-scales of the ecological botanist and the geologist are so completely different that they simply do not meet anywhere except in the present! In a country of stable topography the tendency is for the formative processes to be stronger than the destructive ones. In other words, we can look for stable soil conditions and a tendency towards improvement rather than retrogression in any plant cover as ecologically classified, under all geological conditions except actively unstable ones such as landslides, torrent screes and deltas, sand-dunes, &c. The normal geologic process of erosion is therefore on the whole a beneficent one, and even with the partial plant cover of arid regions, the natural balance of precipitation and cover is sufficiently stable to reduce erosion to a negligible rate.

Accelerated Erosion.

Where we find active deterioration of the plant cover in an ecological sense, accompanied as it inevitably is by changes in the soil texture and in the underground water-table level, we must look for the reason either to climatic changes or to biotic factors such as man and his actions. When the normal balance between precipitation and cover is upset, the erosion process is likely to be greatly increased, and accelerated erosion, which can no longer be considered as a purely geological phenomenon, takes place. Accelerated erosion cannot be completely identified with ordinary geological processes because it falls outside of them. A knowledge of geology does, however, serve to help the field worker to recognize this erosion, provided he is prepared to think in terms of botanical and not geological time-periods. For each of the three slope profile classes outlined above, there is a corresponding type of accelerated erosion (Fig. 3).

(a) In the arid climate type there is no very marked alteration in the soil or vegetation of the higher slopes, but the increase in run-off and load of detritus which these slopes contribute to the stream may start a new cycle of erosion in the beds of the larger streams which cut down through the soft alluvial beds of the adjoining plains, thereby draining out any water-table which these previously held. A characteristic of many such alluvial lands is the riverain forest which persists with occasional inundation or with the help of underground water; with the cutting of a deep channel both these sources of water supply are destroyed and the riverain forest dies out. Changes in the water-table are

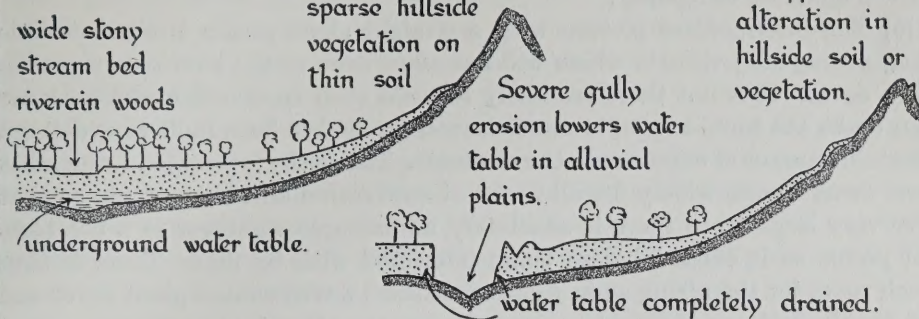
NORMAL GEOLOGIC

PROCESS

a. ARID CLIMATE. SLOPE CONCAVE

wide stony
stream bed
riverain woods

sparse hillside
vegetation on
thin soil



Little appreciable
alteration in
hillside soil or
vegetation.

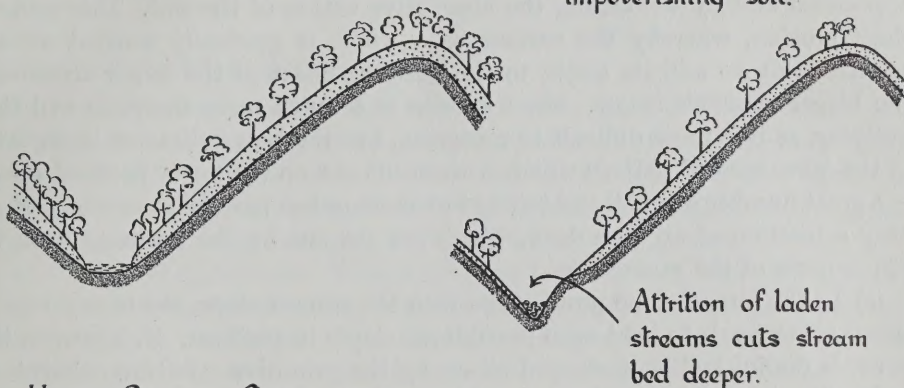
Severe gully
erosion lowers water
table in alluvial
plains.

water table completely drained.

b. INTERMEDIATE CLIMATE. SLOPE STRAIGHT

Weathering & soil building
balance with soil removal.

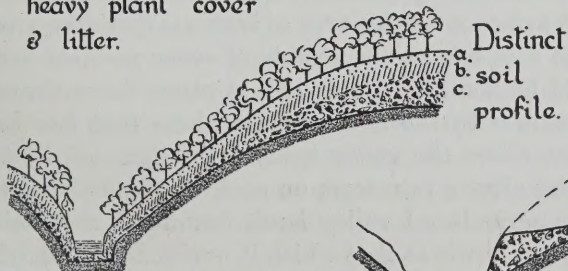
Reduction in plant cover
leads to sheet erosion on
all slopes thinning and
impoverishing soil.



Attrition of laden
streams cuts stream
bed deeper.

c. HUMID CLIMATE. SLOPE CONVEX.

Soil completely protected by
heavy plant cover
& litter.



Distinct
soil
profile.

Profile
reduced
through
loss of a.

Soil creep & stream bank
erosion is geologic normal.

Any destruction or
diminution of plant cover
leads to washing soil from
higher slopes & gullying of lower ones

CHARACTERISTIC SLOPE PROFILES

J.S. SHAW.

FIG. 3.

sometimes indicated by a change from a grassland type to deep-rooting trees or bushes of the 'phreatophyte' or well-plant class such as the mesquite (*Prosopis glandulosa*), whose roots go so deep that they are independent of the surface moisture altogether.

(b) The intermediate picture with a straight slope profile is characteristic of an average dry climate which will not allow even at the best a very prolific plant cover. It is not therefore likely to yield such spectacular results as are seen under the humid type, because the soil profile has been built to withstand a certain amount of exposure to the elements. This is the type of land which has been cleared most widely for all forms of cultivation and for pasture, so that over very large areas there is absolutely no example whatever of a complete soil profile as it existed before being interfered with by man. There is thus much room for theorizing as to what constitutes a true climax plant cover and soil profile, and one is forced to depend upon the often inaccurate accounts of 'oldest inhabitants' and 'early settlers' for an indication of the changes which may have taken place. Reduction in plant cover, puddling by animals trampling, and plugging of the soil pores by clay borne in solution, all have much the same effect upon run-off; they increase its pace both by reducing mechanical opposition and by weakening the absorptive action of the soil. This leads to sheet erosion, whereby the surface as a whole is gradually washed off and carried away to add its quota to the gullying effect of the larger streams in the bigger channels below. Sheet erosion is a much more insidious evil than gullying, as it is more difficult to recognize, but the best indication is probably in the 'shoe-string' pattern which is often cut out on the lower parts of a slope—a great number of small and twisty but more or less parallel channels, perhaps only a fraction of an inch deep, which are cut out by the drainage from the upper parts of the same slope.

(c) In the humid slope profile type with the convex slope, the heavy vegetational cover tends to hold even precipitous slopes in position. If, however, this cover is diminished or destroyed either by the primitive 'shifting cultivation' so familiar in all backward communities, or by fire or heavy grazing, the steep slopes can no longer remain stable and the disintegrated soil is swept downhill, leaving the subsoil in all stages of disintegration down to the bare rock exposed by gullies of varying depth. A symptom of this type of action is therefore a very varying texture of the surface soil, because it consists of every possible variation from remnants of the old horizon, if any are still in place, down through various stages of unweatheredness to the mother rock where that has been exposed. Farther downstream where the valley widens, the immense load of detritus which the river carries after a rainstorm on such unstable slopes will be deposited in the forest or agricultural valley land, forming a new valley floor which may or may not be as fertile as that which it buries, but destroying property and killing out existing forests by cutting off the trees' root aeration.

Losses from Ploughed Land and Grazing.

There are two essentially different sources of erosion damage, the one arising from cultivated areas, the other from grazing lands. Recent estimates for the United States put the area of cultivated land ruined or badly impoverished by erosion at over 100 million acres, and the loss from the impoverishment of range

lands through over-grazing and erosion is reported as 40 to 90 per cent. throughout the 415 million acres of unreserved public lands. Both of these erosion sources are therefore of first-class economic importance in the United States, and although no similar figures can be quoted for other countries, there is no doubt whatever that they do both occur almost universally, and are at their worst in the thickly populated semi-tropics where farming and animal husbandry are both very primitive.

Where shifting cultivation is practised the soil losses must far exceed even the most thriftless western methods, such as the summer fallow for wheat which is responsible in the rich Palouse soils of Washington State for a loss of 50 tons of soil per acre per annum. On the other hand, the usual Oriental field system of narrow level strips, each with its outer ridge to retain the rain, is probably more efficient in preventing run-off than any other. The fact that many such fields have been in use for centuries is proof of this. Farm erosion is obvious and can be accurately measured; grazing land erosion, however, is more insidious and difficult to measure or prove to the stock owner, for nobody ever admits to over-grazing his own land, although he is quite prepared to allow that his neighbour does!

Examples of the Effects of Over-grazing.

Two examples only will be dealt with, one from the Old World and one from the New, as an indication of the conditions which will be found throughout most of the drier and hotter countries of the world. The examples quoted are extreme, but they may indicate how the initial stages of the same process elsewhere can be recognized and dealt with before they get any worse.

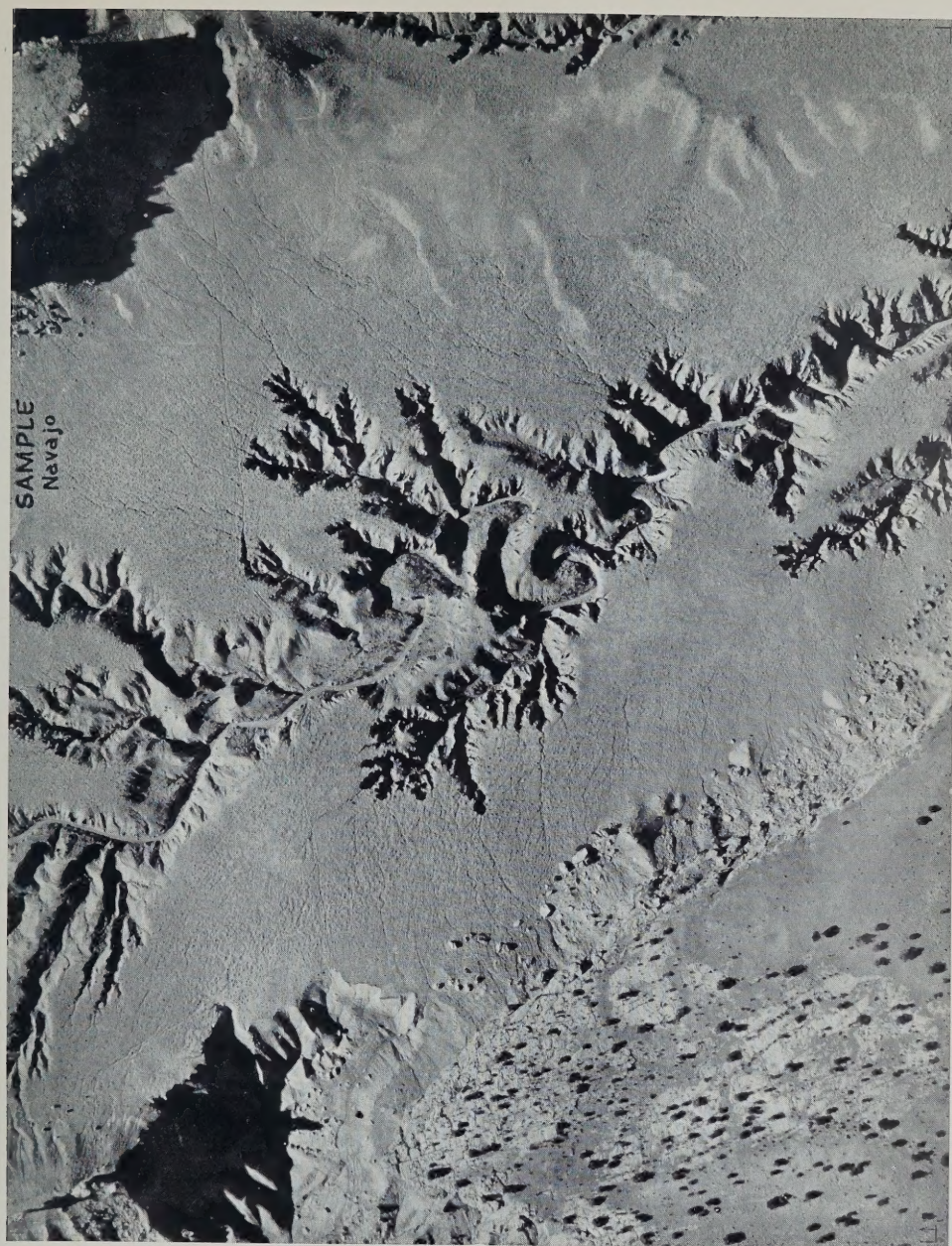
A. *The Punjab Siwaliks.* This is a country of dry foot-hills of porous conglomerate and sand-rock rising from the Indian plains and merging gradually into the higher Himalayas. The natural plant cover is a scattered growth of low trees such as *Acacia catechu* and *Anogeissus latifolia* with a heavier bush growth of *Mallotus philippinensis* and *Dodonea viscosa*, and perennial grasses like *Ischoemum angustifolium*, but over large areas the process of destruction has been so complete that literally no vegetation is left whatever. The rainfall is a fairly regular monsoon of about 40 inches with erratic light winter rains. Historical records show that this was under fairly dense forest, used by a scanty population of graziers, and until the introduction of British peace and protection about 1850 these had very little chance of developing or increasing. Since then, however, the pressure of local increase combined with the influx of large itinerant herds of goats and dairy buffaloes has placed a cumulative load on the grazing resources, combined with lopping for fodder, fellings, and annual fires.

In the late 'seventies the dangerous condition of the tract was recognized by Mr. J. Coldstream, the local civil officer (who incidentally coined a useful word 'geoteresy' to cover all operations connected with the protection of the earth's surface against erosion), and by Mr. Baden Powell, conservator of forests. The latter's report of 1879 shows that the villagers even then realized that a serious deterioration had occurred in their land. 'To see that splendid district, yielding a revenue of nearly 14 lakhs annually, and yet to observe how mile

after mile is cut up with the broad beds of sand, not only useless, but spreading their desolation farther and farther with every hot wind and every flood, would certainly argue powerfully that a moderate expenditure to stem such an evil is better than letting the steady if small loss of revenue that goes on accumulating continually, remain unchecked and uncared for, till some day we wake up to find that the evil has slowly extended to a point either beyond our control, or to one that will cost millions to remedy when thousands will now suffice.' Unfortunately this is exactly what has happened. A Chos Act passed by the Punjab Government in 1900 led to some minute areas of the upper slopes and the outer crests adjoining the plains being afforded partial closure to grazing in Hoshiarpur. These and some forests owned and conserved by two local landowners, the Mir of Morni and the Raja of Kalsia, have been saved from destruction, but in the adjoining Ambala foot-hills the position is everywhere desperate (23 and 24). The area of absolutely sterile sandy *chos* in Hoshiarpur alone has more than doubled since 1852, and now covers over 50,000 acres.

Other agencies have of course taken a share in this wasteful exploitation of what might have remained a valuable natural resource; periodic droughts in short cycles of sub-normal rainfall such as occurred in 1917 to 1921 do some damage, but there can have been no appreciable change in the climate during the last thousand years; fires are common, though not nearly so common as they are in the *Pinus longifolia* zone a little higher up the hills; and cultivation has been extended in some villages. But the main and responsible cause for the deterioration is over-grazing, as can be seen very clearly from the grazing incidence figure for the available foot-hill land in Hoshiarpur district, the average being 4.3 head of stock to the acre, three-quarters of which are cattle, one-quarter sheep and goats. A comparison with any normal live-stock capacity figures for similar rather sparse feeding grounds under reasonable management will show at once what a colossal overload of grazing this is. Immediately to the east and just across the Jumna river, the Saharanpur Siwaliks with approximately similar climate were constituted a government reserved forest and have enjoyed efficient protection during 70-odd years. A large revenue is derived from grazing and lopping permits, the sale of *Ischoemum* grass for paper-making, and the felling of timber, fuel, and bamboos; its productive condition is a striking commentary upon the Punjab government's failure to deal with a similar situation.

B. *The Navajo Indian Reservation, New Mexico.* This is an area of 16 million acres in the Colorado Basin which was allotted in 1868 to the remnants of the Navajo (pronounced 'nava-ho') tribe of Indians, then numbering only about 8,000 people at the close of the Indian wars. It consists largely of rolling hills of open *piñon* pine (*Pinus edulis*) and juniper interspersed with alluvial flats, in the better of which the Navajos practise a primitive form of irrigation. The rainfall is low, in the neighbourhood of 20 inches, but divided fairly equally between summer thunderstorms and gentler winter rain, so that the vegetation is of a much higher type than is generally imagined of this part of the 'desert'. If given a fair chance it will produce a reasonably good cover of open bunch-grass, such as was found on it originally by the Spanish conquistadores and the early settlers. Even after discounting a little for the enthusiastic exaggeration of these pioneers, this country must have been very productive in cattle and



An aerial view of Navajo grazing country where deep gullying has developed following the destruction of the ground cover of bunch-grass by over-grazing. Photo by courtesy of Fairchild Aerial Surveys Inc., Los Angeles

sheep fodder, and even up to 20 years ago the Navajos cut good hay crops which they sold to the shopkeepers of Gallup and other neighbouring settlements.

To-day their flocks have increased to well over a million head and their population of 47,000 is on the verge of starvation, because their only natural resource, the grazing, has been destroyed. Their only industries are live-stock, some spinning of wool, and a little primitive irrigation farming; the live-stock and the production of wool can only be maintained if the grazing is allowed to recover, and irrigation is becoming increasingly difficult in view of the widespread gullying of valley flats by the increased run-off from the impoverished hill slopes. The whole reservation has literally been turned into a desert by the cumulative effect of over-grazing: 'Once productive valleys are cut to pieces by ugly gullies; corn-fields and squash-patches formerly irrigated by the simple method of flood-water farming are rendered valueless because the water-courses, large and small, have become wild and uncontrollable; slopes and valleys that produced abundant forage are given over to worthless weeds or bare ground because, deprived of the vegetative mat that once held back the water and filtered it into the soil, they now act as roofs over which the water flows in sheets to the gullies. Because of over-stocking and an undue proportion of goats, the browse cover has been nearly destroyed. The piñon, that valuable nut-bearer whose great crops have been one of the Navajo's income producers, is gradually disappearing because the goats destroy the seedlings and the mature trees are being consumed for fuel. The recurrent droughts which once held no terror for the Navajo now deprive him of income and hasten the depletion of the land. Where antelope, deer, and wild turkey were once abundant, over-hunting and over-grazing have made them non-existent' (25).

The neighbouring Coconino National Forest with a very similar climate and vegetation has been under range management for some 30 years, and although fully utilized by large herds of cattle, continues to carry a cover of pine, juniper, grasses, and sage brush which, though far from complete, is sufficient to prevent any excessive run-off. Accelerated erosion is therefore not in evidence, though it is making itself apparent to some degree in neighbouring private ranches where grazing is less conservative (see frontispiece).

Climatic Fluctuations a Contributory Cause.

In both of these examples there is room for debate as to how far a gradual desiccation of the climates of these areas has contributed to the results described. In the case of the Punjab, it has been suggested (26) that a gradual but sweeping increase in aridity proceeding from west to east along the Himalayan foot-hills must be held partially responsible for certain ecological changes in *Shorea robusta* forests of a trend similar to the foot-hills desiccation. This, however, is not borne out by other estimates of climatic change, such as the continued cultivation of the same unirrigated crops on the plains for many hundreds of years, the ecological stability of the forest types in the higher hills unaffected by heavy grazing, and by recent meteorological evidence from the rise of the water level in Ladakh lakes being due to increased rainfall in the inner Himalaya (27). It is hardly conceivable that the foot-hills rainfall could be falling off if that of the plains on one side and the high hills on the other is not doing so. On the other hand, the whole of these foot-hills are suffering

from a very general desiccation, and the continued failure of wells has been a subject of remark in annual reports for the Punjab, and has been the reason for considerable emigration from foot-hills villages. The reason for all this is not a climatic change but merely the gradual destruction of the vegetative cover.

In the case of the Colorado Basin there has been a very marked acceleration in the deepening of stream beds throughout most of Arizona and New Mexico since about 1880, and this has been critically discussed on the basis of geological and meteorological changes by the geologist Mr. Reed Bailey (28). The deepening of so many *arroyos* (beds of intermittent streams) has decreased the irrigable area previously cultivated with a primitive system of flood-water farming; it has also ruined the pasture value of many flat riverside meadows by draining away the underground water-table; it has caused the abandonment of numerous ranches and small towns throughout the dry south-west, and has caused local but exceedingly serious torrential mud-flows. There is conclusive geological evidence, such as the fresh channelling out of the Bonnevillite lake deposits which have previously remained undisturbed for many thousands of years, that some disturbing factor has brought about this new epicycle of erosion.

Three possible causes are (i) diastrophism—a local shifting of the earth's crust; (ii) a change in climate; or (iii) a change in plant cover; and in summarizing these, Mr. Bailey writes: 'The destruction and modification of the plant cover by over-grazing appear to be the dominant cause of the recent epicycle of erosion. It is the one known change that has occurred throughout the province capable of reversing gradational processes. The formation and maintenance of soil on the slopes and of alluvium in the valleys, in a topographically young region having an erratic climate, is accomplished by a delicate adjustment between the factors that control gradation. When the plant cover, one of the controlling factors, was materially reduced and modified, this adjustment was disturbed, resulting in more intensive run-off from the slopes and down the valleys which eventuated in a reversal in the gradation process. No doubt erratic rainfall, the nature of the topography, and the character of the alluvium have contributed to the rapidity with which the erosion has progressed, but there is no persuasive evidence that they are the major causes. The lack of any change in the gradation of naturally barren areas . . . constitutes evidence that there has been no effective change in quantity or rate of rainfall. The sequence of settlement, with its attendant heavy utilization of the vegetation and inception of channelling of the valleys, strongly supports the conclusion that destruction and modification of the plant cover is a major cause of the present epicycle.'

Another geologist, Mr. Kirk Bryan (29), draws a parallel between the present cycle of accelerated erosion and the decline of the local prehistoric Pueblo culture which was apparently accompanied by a similar cycle of increased erosion. He considers that the ultimate cause of the present accelerated erosion may be found to be a repetition of such a cyclic fluctuation in climate, but that the loss of the vegetative cover through over-grazing has been the 'trigger pull' which has fixed the date and precipitated the change.

It is evident from these discussions that the possibility of climatic changes and cycles affecting the average rainfall and therefore the stability of the vegetational cover does have to be carefully considered, but there is so little

reliable evidence about such long-term changes in climate that the question is of theoretical rather than practical interest. What is of more practical importance is to realize that erosion cycles are more likely to be initiated by one really phenomenal storm which may occur once in perhaps 50 or 100 years, rather than by any slight alteration in the average over a long period. An example of this was seen in the terrific rain which fell on the western Himalayas in September 1924, registering 27 inches of rain in less than 36 hours for foot-hill areas whose annual average was about 60 inches, and 10 to 12 inches in 3 days in arid tracts of the inner hills whose normal is 15 to 20 inches mostly in snow-fall. In such cases the damage is in inverse ratio to the capacity of the plant cover to deal with such unexpected quantities of water, and in the inner hills many gullies were wrenched out of previously stable hill-sides, and have continued to erode in the subsequent 10 years. Thus this one phenomenal down-pour has apparently started off a new cycle of erosion, as there is little or no sign of these gullies healing up. Mr. C. G. Bates also quotes local opinions of Wisconsin farmers to show that the beginning of serious erosion is often associated with one year of unusual rainfall (30).

Conversely a prolonged and unusually severe drought is likely to affect the protective value of the vegetative mantle much more seriously than a consideration of the average drought period over a long series of years, particularly if it is marked with an outburst of unusually severe and widespread forest and grassland fires such as occurred in northern India in the summer of 1921 at the end of three particularly poor rainfall years.

Reduced Productivity of Eroding Range Lands.

The well-known effect of a plant cover absorbing and delaying the run-off from rainfall is due largely to the fact that it maintains the sub-surface soil in a friable condition under a mulch of decaying vegetable matter, part of which eventually combines with the mineral fraction below to build up a soil profile. This process is exceedingly slow in an arid climate and the trampling of livestock must obviously interfere considerably with this action. The compacting of the ground when it is wet and the scattering of the surface when it is dry and powdery are both aggravating factors, because both tend to increase the rate and volume of the run-off from any subsequent rainstorm. Soil pulverized into a dry powder has a further bad effect when it is taken away in suspension by run-off, because its clay fraction acts as if it were a paste spread over the ground surface, sealing up the pores and spaces which should be functioning by transferring moisture to the deeper layers of the soil. Dr. W. C. Lowdermilk has shown that by introducing 2 per cent. of sediment into water and percolating this through a soil surface, the rate of percolation fell off 90 per cent. in 6 hours as compared with clear water; and reverting to the use of clear water did not accelerate it afresh.

In addition to robbing the top soil by its mechanical removal of soil particles, accelerated erosion has been proved to remove a relatively greater amount of soluble chemicals vital to the plant—in other words it robs the soil still *in situ* of its chemical properties before it actually washes it away. This is borne out by figures supplied by Professor A. W. Sampson from experiments carried out by him some years ago at the Great Basin Station, Utah. Wheat grown in pots

containing soil from eroded and uneroded spots under spruce at 10,000 feet of the same origin and sifted for this experiment, gave the following data:

	<i>Eroded.</i>	<i>Non-eroded.</i>
Water-holding capacity	46.8 per cent.	67.2 per cent.
Loss on ignition	6.6 „	14.6
Dry weight of wheat grown	5.5 lb.	12.1 lb.

Other tests showed that non-eroded soil was much richer than eroded soil in lime, phosphoric acid, and total nitrogen; the water required by representative plants to produce a pound of dry matter was less for the non-eroded soil (31). Samples from similar soils degraded by heavy grazing as measured by other workers for two areas in Utah gave the following figures for nitrogen content (32):

	<i>Area 1.</i>	<i>Area 2.</i>
Non-eroded soil	0.337 per cent.	0.382 per cent.
Partially eroded surface	0.258 „	0.202 „
Badly eroded surface	0.088 „	0.043 „

One would expect such losses to be more serious on the shallow soils of typical grazing lands with sharply diversified soil profiles than in the deeper, more uniform soils of cultivation, but Eden (33) quotes convincing figures to show loss of nutrients caused by erosion in crop lands. An eroded surface thus presents both a lack of moisture and of plant nutrients which together must be detrimental to plant growth and to seed production, and the familiar grazing land picture of poor vegetative growth, poor seed production, and a high mortality amongst any seedlings which do appear, is borne out by these and other similar data which have been collected to show to western stockmen how they are wasting the basic soil resources on which their industry depends.

It is a commonplace amongst stockmen on many ranges to remark that their range is 'worn out'—that it will not carry as many animals as it once did—as if some outside influence beyond their control had deprived them of their livelihood, whereas the actual cause is persistent over-grazing which has led eventually to the sheet erosion and degraded condition which is only too typical of grazing grounds in almost every country. That conditions can be improved by simple closure is shown by figures from two comparable catchment areas which have been kept under observation for 15 years at the Great Basin Station in Utah with the main object of measuring the relative efficiency in terms of erosion of pastures under different treatments.

Wasatch Plateau Grazing Study (34).

The two water catchments of about 9 and 11 acres were located and equipped so as to permit measurement of precipitation, run-off water, and sediment carried. One of them, *A*, had a rather badly broken surface as a result of previous over-grazing which had reduced the plant cover to only 16 per cent. The other, *B*, which was in the nature of a control, had retained its cover rather better, though it also had been fairly heavily grazed before the experiment began. Its plant cover of 40 per cent. was in a much more stable condition than that of *A*. During the first 5 years *A*'s cover was kept at the 16 per cent. figure, then *A* was closed to grazing and revegetation was helped by sowing of grass until it caught up with *B*, which had meanwhile been grazed just enough to hold it at the 40 per cent. figure.

The rainfall of 30 inches is divided, with summer rain in May and June and winter snowfall, the elevation being 10,000 feet. The two areas are not absolutely comparable from the point of view of contours and run-off, because although of approximately the same shape and slope, *A* has one main drainage channel with a lot of small gutters running obliquely into it, while *B* has no main channel but a series of small independent parallel gutters. In point of vegetation also they are not absolutely the same, because although *A* has caught up with *B* in the actual percentage of surface covered by plants, it had been previously so badly degraded that the type of plant growth is even now hardly as stable as *B*'s is. Aside from these minor points, however, the areas are roughly comparable and the measurements over such a long period give some exceedingly useful information, as the run-off and sediment have been measured for each storm since 1915. The experiment is still in progress, as the roles of the two areas are being reversed.

The results on a ratio basis between the two areas showed that with the increase from 16 to 40 per cent. cover, *A*'s surface run-off was reduced 64 per cent., the reduction being almost entirely in the 'flash' run-off from sudden summer rains and having no effect upon the winter snow melt. With a 16 per cent. cover the 4.6 per cent. share of annual total run-off caused 84.5 per cent. of the erosion; the remainder of the run-off which was from melting snow caused far less erosion; after vegetation had increased to 40 per cent. the summer rain run-off fell to 1.3 per cent. of the total. For the three 5-year periods the run-off was 10.33 per cent., 8.74 per cent., and 5.49 per cent. of the total rainfall on *A*, the area with the poorer plant cover, as compared with 4.10 per cent., 2.88 per cent., and 1.05 per cent. for *B*, which was continuously better vegetated. Comparing the first and third periods, the total sediment eroded from *A* decreased by 46 per cent. and the amount carried in each 1,000 cubic feet of run-off water decreased 57 per cent., due to the improved plant cover.

The results indicate the importance of a vegetational cover and the difficulty in reconstituting the soil and cover in its former condition once it has been to any serious extent degraded by over-grazing and erosion. The figures cannot be taken as being generally applicable, but they give an indication of how local conditions can be visualized once such data are available. There is great scope for such measurements wherever grazing resources are in danger, because actual figures are invaluable in educational work and publicity amongst farmers, so this particular experiment should be of considerable value to all who are initiating similar work elsewhere.

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IV. VALUE OF VEGETATIONAL COVER IN STREAM-FLOW CONTROL

Man's Dependence upon Water Supplies.

ALMOST every human activity is limited in some fashion by lack of water, whether it be in the form of domestic or industrial supplies, irrigation, water-power development, navigation, or merely what you put in the radiator or the teapot! Densely populated cities are being forced to go far afield for their requirements, and vast sums of money are being spent in every country upon engineering works to utilize local water resources for industry and agriculture. India has some 50 million acres under irrigated crops. The United States census of 1930 showed that for 19½ million acres under irrigation they have an investment of nearly 6,000 million dollars in the value of buildings, machinery, reservoirs, and land for irrigation enterprises. Irrigation water is of very definite commercial value, as it is the life-blood of many great communities. To quote only one instance, the 350,000-acre irrigation area supplied by the Boise River in Idaho derives its water from a catchment area of 1,700,000 acres; the money invested and dependent upon this catchment places a responsibility valued at 32 dollars an acre upon it, apart altogether from any other direct forest revenue which is being derived from it. The source of such wealth should, one would imagine, be given some attention and respect, but it is astonishing what faint interest is taken by either the irrigation engineer or the farmer in this matter. The water is just taken for granted.

Stream-flow Values.

It is only in exceptional circumstances that the entire stream-flow of a river can be used by man; in most rivers a very large percentage is lost in uncontrollable floods. The measure of a stream's efficiency to meet our needs is its *average flow*, and in the case of domestic supplies, *average clear-water flow*. Any

factor which interferes with the regularity of this flow is of importance. The information given in the previous chapter dealt primarily with erosion, and it is now proposed to discuss stream-flow, but the two are often difficult to separate in so far as floods and flood damage are concerned, because any increase in run-off from rain will tend to increase the erosive effect also, and floods are the result of the cumulative effect of both.

The gauging of streams will give some useful indications of stream values, and meteorological information may serve to warn when floods may be expected, but the only way to get a complete and accurate picture of stream behaviour is to study the absorptive efficiency of the various types of ground and ground cover which comprise the catchment basin, and the contribution in run-off water and sediment which these are likely to yield when storms come along.

The laws of hydraulics and text-book asseverations that 'the erosive power of water varies as the square of the velocity and the power to transport this material as the sixth power of the velocity' do not serve any useful purpose—as we found to our cost after many weary hours spent in the translation of parts of Wang's *Grundriss der Wildbachverbauung*! Floods and torrents can do incredible things, and the capacity for damage of a viscous mud-flow such as sometimes pours out upon orchards and villages from the mountain catchments of the Wasatch and Haute Savoie must be seen to be believed. There has been much inaccurate writing about the causes and cures for floods in most countries, but there have previously been no examples where sufficient data about rainfall distribution and intensity, and the relative value of soil types and covers, were available to give a really complete picture. One has now been obtained in California, and will be discussed in detail.

The La Crescenta Flood, Southern California (35).

One of the activities of the California Forest Experiment Station is the study of rainfall, stream-flow, and erosion, as California's dry climate, dense population, and water demands all tend to make the available water very precious. Accordingly the foot-hills of the Los Angeles National Forest immediately to the east of the Los Angeles residential suburbs had been well studded with rain-gauges and enclosed plots of various sizes in which the run-off and sediment loss could be measured. A storm on New Year's Day, 1934, fell generally over southern California foot-hills and valley lands in a belt about 20 miles by 50; within this area the total varied from 8 to 19 inches, but all the foot-hill catchments involved had very close to 12 inches. This was not by any means unprecedented, the only unusual feature being that the foot-hills got a larger share than the higher altitudes, the usual fall being roughly proportional with increasing height. This foot-hill belt included an area of 5,000 acres of the Verdugo valley which had been burnt 2 months previously, the rest having been successfully protected against fire for a number of years. The foot-hill cover consists of chaparral forest of scrub oak and a dense bush growth of *Ceanothus*, *Arctostaphylos*, *Rhus*, and *Adenostoma*, with larger trees of poplar, alder, and sycamore in the deep sheltered canyons. The fire was a severe one and in addition to killing off the plants reduced the litter to a powdery ash several inches deep. Floods from the Verdugo stream did a tremendous amount of damage in the La Crescenta and Montrose townships,

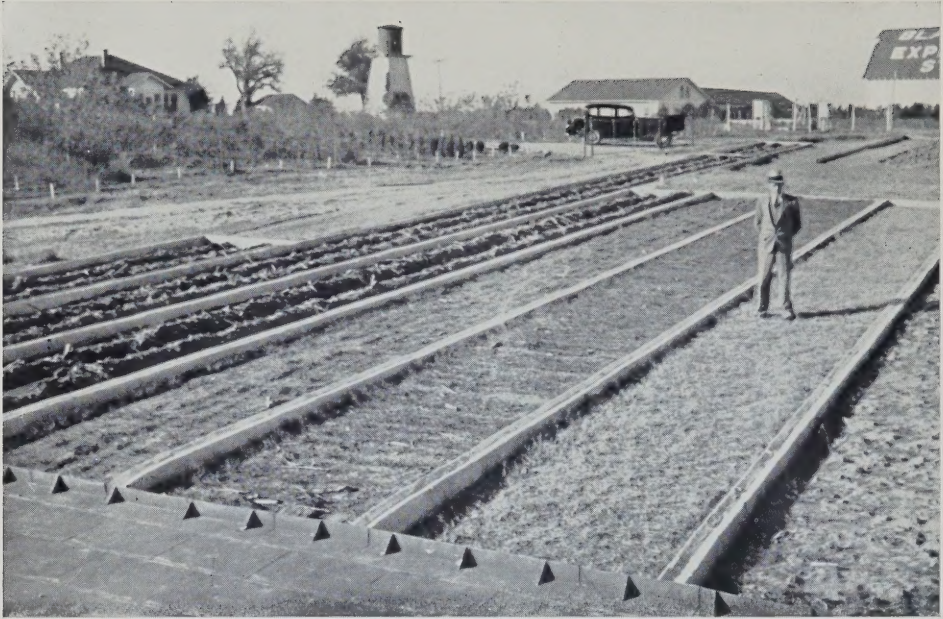
including the loss of 34 lives, several hundred houses, and the complete burial of hundreds of acres of fine fruit gardens under several feet of raw rock debris. More than 12 inches of rain fell on several other neighbouring valleys, but they did not flood to any great extent and no appreciable damage was done, although they are all steep canyons rising in the San Gabriel range and dropping within 2 miles from 5,000 to 2,000 feet. The small Pickens Canyon had lost the whole of its cover in the fire, and the Verdugo 4,000 out of its mountain total of 6,000 acres, the plains section of 8,000 acres being untouched. Some 30 stations in this area registered an average of 13.03 inches, 7 on the Verdugo registering 12.56, from which it will be seen that the rainfall was certainly no heavier on the damaged area than it was elsewhere. The rain fell during 63 hours, intensity records showing 0.88 to 0.94 inch in 1 hour for the Verdugo valley but rising to 1.33 and 1.29 inches for other foot-hill areas. As the generally accepted definition of 'cloud-burst intensity' is a 3-inch fall in 1 hour, it is obvious that this storm could not fall in that category.

The outstanding lesson from this flood is in the contrast in run-off and erosion between the burned and unburned catchment areas receiving the same rainfall. This shows that the condition of the ground cover of catchments is the major influence in causing disastrous floods in the rivers which drain them. Steepness of slope, geological composition, intensity of rainfall, also enter the picture, but the plant cover—or lack of it—is the most important, and the only one over which we have any control.

TABLE 1. *Erosion Measurements from La Crescenta Flood*

Watershed.	Rainfall inches.	Area sq. miles.	Per cent. water- shed area.		Peak run-off cu. ft. per sec. per sq. mile.	Erosion cu. yds. per sq. mile.
			Burned.	Unburned.		
Burned Verdugo .	12.5	19.30	33	67	320	30,700
Unburned San Dimas . .	10.8	16.85	..	100	53	56
Burned Pickens .	12.5	0.48	100	..	1,000	50,000
Unburned Fern and Bell . .	12.4	0.30	..	100	25	52

The figures of 320 foot-seconds run-off and 30,700 cubic yards erosion per square mile for Verdugo are calculated by dividing the total amounts of run-off registered and debris deposits surveyed by the total area, only one-third of which was burned; its figures are not so striking as in the smaller Pickens Canyon which was completely burned. The very low run-off rate and the insignificant amount of debris shifted from the unburned areas demonstrate how the natural chaparral cover retards and diminishes the escape of rainwater and ensures a clear stream, in striking contrast to the terrific mud spates of the bare areas. The ratio for the small canyons is 40 times increase in run-off and 1,000 times in erosion. The erosion measurements are derived from the deposit left by the flood in the valleys below, and surveyed by the local authorities. The erosion rate of 50,000 cubic yards, enormous as it must seem, is exceeded by an actual measurement of detritus in the case of another small burnt canyon



Standard 1/100 acre run-off plots used by U.S. Department of Agriculture to obtain figures quoted in Table 2. On the left maize with downhill furrows shows heavy loss of rainfall and soil; on the right Bermuda grass shows no soil loss and complete absorption of rainfall



One of the run-off measurement plots used by H. G. Meginnis to obtain the data quoted in Table 3

of 67,000 cubic yards per square mile. These computations from actual measurements of the detritus of a whole valley are in striking agreement with the figures for small plots and rain detention pans which are maintained in Experiment Stations in many parts of the States, both by the Forest and Agricultural authorities.

Importance of Plant Cover in Run-off Control.

The following figures show clearly the very radical effect which a change in the type of plant cover has upon both run-off and erosion for a great variety of soils and climatic conditions. They demonstrate also that the La Crescenta flood figures cannot be treated as exceptional, or as being confined to any particular set of conditions. They are for agricultural conditions, showing incidentally that the question of *forest* cover is of relatively minor importance compared with the main issue, which is the efficiency of *plant* cover as a whole.

TABLE 2. *Run-off from 12 soil types, with and without plant cover (36)*

Location.	Soil.	Slope per cent.	Bare ground clean tilled.		Covered ground grass crop.	
			Soil loss tons per acre.	Water loss per cent. precip.	Soil loss tons per acre.	Water loss per cent. precip.
Bethany, Missouri	Shelby silt loam	8	60.8	27.4	0.3	7.7
Columbia, Missouri	Shelby loam	3.7	19.7	30.3	0.3	12.5
Hays, Kansas	Colby silt clay loam	5	13.2	17.5	0.004	0.04
Tyler, Texas	Kirvin fine sandy loam	8.8	19.1	20.0	0.2	1.5
Tyler, Texas	Nacogdoches fine silt	10	6.1	15.4	0.02	1.4
Guthrie, Oklahoma	Vernon fine silt loam	7.7	28.1	18.2	0.04	1.5
Clarinda, Iowa	Marshall silt loam	9.6	44.6	12.5	1.3	6.5
La Crosse, Wisconsin	Clinton silt loam	16	59.9	19.2	0.003	2.9
Spur, Texas	Abilene clay loam	2	6.1	12.8	1.6	5.8
Temple, Texas	Houston black clay	4	12	11.6	nil	nil
Statesville, N. Carolina	Cecil clay loam	10	13.8	9.3	0.7	5.5
Pullman, Washington	Palouse silt loam	30	31.2	29.8	0.4	0.3

These data have been collected from series of long isolated strip plots in which local cultivation methods can be accurately compared to show their relative efficiency in soil conservation (Plate III). The average shows that grass gives an infinitely greater protection than bare ground, the ratio being 5 times better for stopping water run-off and 65 times better in preventing soil loss.

Classification of Plant Covers and their Relative Efficiency.

The general distribution of natural plant cover types and of the cultivated crops which are associated with them depends chiefly upon the rainfall. They

can be grouped into three geographical classes of arid, intermediate, and humid, corresponding very roughly with the three climatic types of erosion processes previously discussed, each having its own set of problems of stream-flow.

(a) *Arid Conditions.* Below about 25 inches rainfall and down to the desert margin at which plant cover is no longer of any consequence, the characteristic plant cover is a very open one, very easily damaged by prolonged misuse such as over-grazing, but of very real importance in preserving the percolation value of soil, particularly where the scanty rain falls in a series of infrequent torrential downpours. Cultivation is usually only possible with the help of irrigation, so that water conservation is vitally important. Within this group there is no great choice of cover types, and any destruction of the grassland, which is often the natural climax, leads immediately to degradation, which is difficult and often quite impossible to repair, so that the planners of better land utilization will generally have to work on the basis of any cover being better than none at all. There are, however, isolated instances within this zone where (i) some alternatives in type can be arranged, or (ii) where the price paid in water consumption by the vegetation is considered too high for the additional security which it confers in ameliorating the stream-flow conditions.

An example of (i) is seen in the tall tree vegetation of the Californian canyons which, compared with the surrounding low chaparral scrub, does undoubtedly show a high water-use ratio. Measurements have been made in Devil Canyon in the San Dimas Experimental Forest near San Bernardino by Dr. Wilm of the California Forest Experiment Station staff in the diurnal variation of stream-flow at two points in a canyon bottom 1,800 feet in distance apart and with 400 feet vertical difference; the difference in the variation curves for top and bottom stations is taken to represent the water used by the canyon bottom vegetation in evaporation and transpiration between these points. The water used is $\frac{3}{4}$ acre-inch per 1,000 feet of canyon bottom as an average maximum for dry days only; this is based on 370 days in 2 years, all wet and unresponsive days being omitted. Just how this compares with the alternative of low scrub if the tall trees are felled, and what effect their felling might ultimately have upon the underground water table, is not yet known, but it would obviously have some adverse effect upon the soil-building process, because the lower scrub does not produce the same amount of litter, while it and its soil are much more completely pulverized by fires.

As an example of (ii) reference may be made to the Okanagan Valley in the dry interior of British Columbia. I have not actually seen it, but I understand that its irrigation supply is obtained from a catchment area of hard granite, the run-off being almost entirely from melting snow and the topography such that large storage dams are not feasible. Under such circumstances the irrigation engineers maintain that they get a larger total run-off by the annual burning of the vegetation, and the complete removal of all timber, as it is felt that the transpiration by the plant cover is an important factor in reducing the supply, every drop of which can be utilized. Just how far they are correct it is difficult to say, as no local measurements are available, but recent literature summarized by Cabianca (37) indicates that they are wrong. He quotes Serrato as having reported that 'on afforested land (in Mexico) with the litter intact, evaporation represents only 85 per cent. of the comparable evaporation on

lands not so afforested, and that where the litter was removed the proportion fell to 61 per cent.' The whole question of transpiration and evaporation from plant cover under arid climates is, however, a very open one, and points to the need of much further research in each district where the issue is of importance, for generalizations in a matter of this sort are exceedingly dangerous.

The study of water movements in desert soil has produced some interesting data to illustrate plant activities under arid conditions. Dr. F. Shreve of the Carnegie Desert Laboratory, Tucson, Arizona, made observations (38) for a rainfall of 12 inches and a distribution of a torrential summer maximum and a weaker winter fall very similar to Rajputana. The greatest single daily fall was 5 inches, which is 80 per cent. of the lowest annual total. In the warm months a period of 3 weeks without rain will kill out herbaceous ephemeral plants and check the activity of bunch-grass and small shrubs, but 3 months without rain will have little effect on *Prosopis* and *Acacia greggii* whose roots may be 30 feet down. The run-off from the percolation plot varied from 5 per cent. to 39.3 per cent. of the total annual rainfall; neither the amount nor the percentage run-off bears any relation to the total rainfall. The first heavy rain of summer falling on a parched surface yields an unusually heavy run-off—e.g. in 1930 a rain of 1.08 inches with a peak intensity of 0.031 inch per minute gave a run-off of 0.81 inch. For a level surface without vegetation the duration and the intensity of the rain determine the amount of run-off, the moistness of the surface at the time of the rain having very little to do with it. The winter rains are far more effectual than the summer ones in building up the moisture of the soil, but an extra heavy winter rain was followed by a very heavy loss in evaporation as far down as 5 feet, which Dr. Shreve assumes is due to the better system of capillary films from the surface downwards than had existed previously.

(b) *Intermediate Dry Conditions.* This class includes all rainfall of 25 up to 60 inches, and therefore includes the majority of the world's great agricultural populations and a large proportion of its temperate coniferous and semi-tropical deciduous forests. (These marginal limits of rainfall have been very arbitrarily chosen, and obviously cannot be applied too literally. The classes cannot be sharply divided.) Conditions for vegetation are such that a fairly large choice of agricultural crops is possible, and even the natural cover can be interfered with and modified by afforestation of exotics, &c., up to a point, without incurring any serious alteration in run-off. Moisture is more plentiful and irrigation of crops less necessary than in the arid class, so that the largest water demands are for domestic and industrial purposes. Flood prevention is very vital, and as many urban supplies are derived from deep underground water resources which are built up by percolation, the general need is for stream-flow regulation and control rather than a rigid economy of the surface supplies.

The relative efficiency of different agricultural crops and methods of cultivation is of very great importance as so much of this class is cultivated. This will be dealt with in Chapter VI from the standpoint of erosion control, but as a great deal of new data are now available to indicate the relative efficiency of various cover types, both natural and artificial, some figures of run-off are quoted from small-scale plot measurements:

TABLE 3. *Run-off and Water Absorption for Loessial Soils, Holly Springs, Mississippi.*

Plot.	Individual rainstorms. Number.*	Total precip. Inches.*	Quantity of rainfall that				Soil lost per plot. lb.	Relative quantity of soil eroded.	Rainfall req. to erode 1 lb. per plot. Inches.
			was absorbed.		ran off.				
			Inches.	Per cent.	Inches.	Per cent.			
Oak forest†	103	134.21	133.18	99.23	1.03	0.77	0.075	1	1789.47
Broomsedge field† (<i>Andropogon scoparius</i>)	103	126.50	125.12	98.91	1.38	1.09	0.305	4	414.75
<i>Robinia pseudacacia</i> and <i>Toxylon pomiferum</i> plantation	97	112.05	109.85	98.04	2.20	1.96	1.676	22	66.86
Bermuda grass (<i>Cynodon dactylon</i>) pasture	92	105.66	101.68	96.23	3.98	3.77	0.311	4	339.74
Scrub oak woodland	102	127.54	117.52	92.14	10.02	7.86	1.089	15	117.12
Barren abandoned land†	103	129.21	67.51	52.25	61.70	47.75	236.961	3519	0.49
Cultivated cotton rows on contour	103	131.38	69.68	53.04	61.70	46.96	114.600	1528	1.15
Ditto on slope	99	126.89	53.04	41.08	73.85	58.20	322.472	4300	0.39

* Difference shown due to fact that in plots where exceptional conditions were seriously disturbed during certain rains, data were not taken for these rains.

† Run-off and erosion data based on average of duplicate plots for first 6 months of study.

‡ (Copied from MSS. of H. G. Meginnis's *Effect of Cover on Surface Run-off and Erosion in the Loessial Uplands of Mississippi* (in press Dec. 1934), by courtesy of Silviculturist, Fed. Forest Service, Washington, D.C.)

TABLE 4. *Storm Record for Run-off Plots, Bent Creek Exper. Forest.*(8 ft. $\times$ 8 ft. plots enclosed by concrete walls with the down slope face open for catching troughs.)

Class of storm.	Inches total precip.	Inches max. ppt. 20 min. period.	Total duration. Hrs. Mins.	Surface run-off expressed in per cent. of total precipitation.									
				Mature oak wood.		40-yr. pine.		Mature hardwood with little removed.		Check plots for 5 and 6.		Open pine & broom-sedge grass.	
				1E.	2W.	3N.	4S.	5E.	6W.	7E.	8W.	9N.	10S.
3-2	0.60	0.18	4 30	3.32	3.98	0	0.25	17.52	2.23	3.53	1.32	..	..
3-2	0.74	0.14	3 0	4.75	4.73	0.01	1.63	43.02	2.21	4.20	2.10	1.31	2.09
3-2	0.68	0.17	3 30	2.18	2.61	0	1.17	8.37	0.19	2.24	1.16	0.52	0.08
3-2	0.95	0.17	5 30	3.37	2.91	0	1.18	26.10	0.90	3.62	2.72	2.35	0.92
3-2	0.54	0.20	2 50	2.94	2.82	0	0.49	36.98	1.62	3.52	3.07	0.93	0.47
3-2	0.68	0.10	2 0	2.57	2.94	0	0.32	57.03	3.80	3.26	2.09	0.37	0.18
Average 3-2	0.69	0.16	3 19	3.18	3.33	0	0.84	31.50	1.82	3.39	2.07	1.09	0.75
3-3	0.55	0.33	1 15	2.70	3.06	0	1.34	13.15	33.89	3.79	2.44	0.95	1.02
3-3	0.63	0.39	45	2.42	5.67	0	0.99	19.30	40.46	4.41	2.51	0.04	0
Average 3-3	0.59	0.36	50	2.56	4.36	0	1.16	16.22	37.17	3.60	2.47	0.50	0.51
4-2	1.09	0.19	7 0	4.93	3.82	0.12	1.11	30.80	13.97	4.95	2.54	1.13	0.72
4-3	1.66	0.27	23 0	3.97	4.28	2.02	0.99	30.16	0.77	3.60	2.20	2.25	0.98
4-3	1.63	0.54	9 20	2.95	3.51	0	0.89	16.51	11.42	4.38	2.57	9.03	12.23
4-3	1.84	1.23	45	4.05	3.91	0.07	2.20	53.70	31.06	4.60	2.02	5.20	8.44
Average 4-3	1.71	0.68	11 20	3.66	3.90	0.69	1.36	33.46	14.42	4.16	2.26	5.49	7.22

KEY TO CLASS OF STORM: Total amount precipitation.

1. less than 0.25 inch.
2. 0.25—0.50 inch.
3. 0.50—1.00 inch.
4. Over 1.00 inch.

Intensity maximum minutes 20.

1. less than 0.10 inch.
2. 0.10—0.25 inch.
3. 0.25—0.50 inch.

By courtesy of Director, Appalachian Forest Experiment Station.

These figures give a good indication of the comparative value of various types, and of the same type under different conditions and treatments. The relative inefficiency of open scrub oak as compared with a more complete oak forest in the same situation, and of mature oak with its litter removed as compared with undisturbed check plots in the same wood, are important, as they show that the relative efficiency of alternative types may not be so vital for stream-flow control as the condition of the type actually on the ground. A striking example of this is seen in the oak woods of the Murree Hills in the Punjab, where economic pressure and increasing numbers of dairy cattle have so swelled the demand for winter fodder that the villagers' tree-logging rotation of 3 years for *Quercus incana* and *dilatata* has been reduced to an annual affair. This speeding up has been too much for the oaks, and the forest has thinned out and deteriorated lamentably. The canopy under light logging was capable of protecting the soil indefinitely, but recent heavy logging, combined with increased grazing also, has led to wholesale erosion, and the oak can no longer function as a hill-top sponge to protect the fields below. Many more similar instances could be given, but unfortunately in none of them in the older countries have any actual data been secured.

The effect of deforestation upon the drier types of forest, and particularly the world's great pine belts, enters largely into any discussion of plant cover values. If the question of the forest's water-use requirements is divorced from that of its effect in erosion control, the matter remains entirely theoretic except in a few exceptional cases of drainage, because firstly these two cannot in the nature of things be separated, and secondly, even if they could, the importance of erosion prevention far exceeds the value of the water which has to be sacrificed as the price for retaining the services of the forest as the conservator of useful water supplies. Where the effect of deforestation upon the stream-flow has been measured it does not give an absolute measure of the trees' water use before they were felled; it merely gives a relative measure of the water use of the young crop which comes up in their place, or of the water saved if no young crop comes in. The Wagon Wheel Gap work by Bates and Henry (39) which has been very widely discussed in technical forestry journals serves a useful purpose in detailing the water-use history of the young crop which came in immediately to replace the felled one, but it does not by any means give a picture of what constitutes 'deforestation' in the wider use of the word—i.e. the inevitable accompaniment of burning, grazing, and dispersal of the remaining plant cover which is popularly associated with the word.

This Wagon Wheel Gap experiment was a very detailed comparative study of two more or less comparable catchments of 200 acres at 10,000 feet in southern Colorado, one of which was clear-felled. The precipitation of 21 inches was mostly snow, and the young growth from the aspen started sprouting vigorously almost immediately. As the area was fully protected there was a barely perceptible increase in stream-flow which disappeared again almost as soon as the dense young coppice was established. Even with quick regrowth, however, the amount of soil erosion which took place from the felled area during the short time it was really denuded increased 15-fold.

Another example of the effect of deforestation on stream-flow is in the Clearwater River in the northern Rocky Mountains. This also had the advantage of

recloting itself almost immediately with brush and herbaceous growth, but the rain-gauge and stream-gauge measurements for 5 years before and 5 years after a serious fire which caused the disforestation of 18 per cent. of the catchment area showed that the April to June flow which is from melting snow increased 11 per cent., while the summer run-off from rain dropped by 32 per cent.; the result of the temporary destruction of the cover was to increase the spring flow, but largely at the expense of the summer flow (40).

(c) *Humid Conditions.* Including all areas with a rainfall above the 60-inch margin, this covers a great deal of the humid tropical areas which have been excluded from the previous discussions on grazing, as they have, speaking generally, got no grazing problem. With water conservation, however, it is different, so they must be brought into this review. Humid agriculture includes most of the tropical and semi-tropical plantation crops such as rubber, tea, coffee, cocoa, quinine, tung, sisal, &c., in most of which the question of some additional crop as a ground cover to check erosion of exposed ground between the bushes is either part of the recognized routine or is under discussion. These plantation crops are not by any means as efficient ground covers as the tropical jungle which has been cleared to make room for them. The effects upon water conservation of widespread clearance of humid forests have not yet been fully appreciated in the countries where this has taken place, although in the cocoa districts of West Africa the more immediate effect of surface desiccation is now being handled. With proper protection of the soil these plantation types can doubtless survive indefinitely, but in the case of the indigenous farming dependent through shifting cultivation methods upon repeated destruction of the natural forest to supply plant food, the cumulative degradation of succeeding rotations of impoverished jungle is bound sooner or later to destroy the hydrological balance. In most cases it has led and will continue to lead to desiccation, for the full force of tropical downpours will fall on ground rendered ever less capable of absorbing it, and a larger proportion will go straight to the sea. In some cases, however, it will have entirely the opposite effect, where large areas of level ground have previously been efficiently drained by the transpirational action of tree cover, and when this cover has been destroyed they have been turned into swamps. Instances of this are known in (i) the South Island of New Zealand, where fellings in evergreen forest for a new agricultural colony led eventually to the farmers being ousted by a swamp; (ii) from the Landes of Bordeaux, where heavy wartime fellings amongst the maritime pine led to a reversion to the marshy conditions which had only been cured a hundred years ago by dune reclamation and pine planting. The fact that the rainfall of the Landes is nearer 40 than 60 inches only serves to prove how very dangerous any generalizations on the effect of forests upon the water-table are; this apparent reversion of the usual role of forests is merely a corollary to the transpirational effect already discussed under California canyon conditions, though it is only under rather unusual circumstances that it becomes a dominant effect in adjusting drainage levels.

Under humid conditions, therefore, the role of plant cover is to absorb and redistribute as much as possible of the total rainfall, which is seldom fully utilized, and to retard the run-off as an insurance against flood damage. As regards choice of cover type, nature will as a rule under humid tropical conditions

insist upon the early production of her local climax vegetation. The stages of ecological succession are so rapid and growth so rampant under these conditions that it is never long delayed on ground left uncultivated; there is therefore very little choice except as between natural jungle and continuous interference with its re-establishment.

Under humid temperate conditions, on the other hand, the process of re-establishment is very much slower, and the effects of the destruction of the plant cover last very much longer. Good examples of this are common in the history of logging operations in the wetter types of coniferous forest, though it is seldom that figures can actually be quoted. To mention only one, Capilano Canyon is a steep mountain valley in the wet coastal belt of British Columbia with a rainfall of roughly 120 inches. It has been operated by the Vancouver Water Board, a private concern which sells town water supplies to Vancouver and other urban areas from this and one other adjoining valley, the Seymour. The lower half of the area is forest of fir, Douglas, and red cedar, which here grows to perfection; the upper half is rock and scree with a little alpine meadow. For a number of years the canyon was logged in sections, an enormous destruction of forest growth taking place for the relatively small amount of timber which was obtained, only the narrow valley bottom being easy to work. The rest of the shattered trees and a great mass of debris remained on the ground, and in some sections was burned. The thin soil on rock outcrops had been wrenched off by the high lead logging, but a good regeneration of brush and hemlock has come in on all the gentler slopes. As each section was logged the local side-streams became seasonal instead of perennial, with a strong tendency to flood suddenly and dry up again. Finally the loggers' railway bridge was washed away, and the water conservation was deteriorating so obviously that the Water Board, having taken 20 years to learn their lesson, bought out the remaining logging lease in order to get the loggers out of the area. With such heavy rainfall it might be expected that brush growth would be so rapid as to prevent serious alteration in the run-off after logging, but this is by no means the case.

Watershed Studies.

In 1932-3 the United States Federal Forest Service carried out, as part of a complete survey of forest resources, a classification of the whole country in terms of watershed values. (Their use of the word 'watershed' to include the whole of a catchment basin is incidentally not according to its English dictionary definition which is 'the dividing ridge which separates two drainages'.) Three classes were used. Half of the total forest area was found to be of major influence, quarter of moderate influence, and the remaining quarter slight or none. Major influence was defined to include steep slopes subject to heavy or concentrated rainfall; areas of excessive snow melt; highly erosive soil where absence of forest would endanger the soil or other land and navigation values. Where irrigation and other demands in areas of scant rainfall made conservation advisable, the forest cover, even though far from complete, was classed as of major influence.

This survey work was materially helped by the fact that there was already established a series of forest climate stations in different areas where detailed study of the effects of forest upon local stream-flow had already been started.



The simplest type of run-off measurement plot, which isolates the surface drainage and soil washed off into the catching-pan



Stream-flow measurement weir of the type used to obtain the La Crescenta flood figures, Southern California (Table 1)

This work has since been greatly developed with the help of relief funds and labour, so that some really reliable data on this very difficult subject should be forthcoming. The three centres I found of most interest in this connexion were California and Arizona for arid conditions, and the Appalachian Station in North Carolina for damper forest country. The object in each case is to collect accurate information on the behaviour of litter and ground cover types in contributing to stream-flow, the occurrence of storms and their effect on peak flows in both large and small streams, and the disposal of the water as between surface and underground drainage and consumption by the vegetative cover itself.

The direct influence of vegetative cover is studied by means of a series of small drainage tanks and plots varying from 500 square inches up to $\frac{1}{4}$ acre, in which surface and subsoil water movement and the erosion process can be seen in action. The total rainfall and the intensity of the fall, evaporation, wind movement, and soil temperatures and moistures at various depths are measured to get a full picture of the fate of all moisture. Various attempts are being made by the periodic weighing of plants growing in lysimeters to find what share of this moisture they are themselves using in terms of transpiration and evaporation. The Appalachian station is measuring the share of precipitation caught and redistributed by the tree cover. Larger drainages of from 2 to 10 acres with uniform cover types are also studied for run-off and subsoil water movement, somewhat on the lines of the Wasatch Plateau watershed studies described above, but aiming at obtaining a series of roughly comparable catchments rather than depending upon one pair, as it is realized that with the underlying strata being an always uncertain quantity, absolute comparability cannot be obtained. Such areas are subjected to various treatments only after some standard of initial comparability has been established. Finally, medium-sized catchments of 50- up to 800-acre units are used for a detailed correlation of rainfall with stream-flow; these consist of different types of measuring weir in which the stream-flow can be recorded by means of a still-well float registering the level on a clockwork dial, the shape of the weir being calibrated so that quantity of water can be read off directly from height readings (Plate IV). The characteristically quiet behaviour and permanence of flow from all areas where the vegetative cover is maintained at anything like its natural condition is already very strikingly apparent, and future data will undoubtedly confirm this essential fact. It is hoped to give a more detailed and technical summary of these forest climate stations and their working in a separate publication.

Rapid Silting-up of Reservoirs.

The situation as regards the silting-up of reservoirs, particularly for the many huge irrigation projects in the dry Western States, is now regarded as very serious. Most of them were built with the knowledge that some silting took place, and their life as estimated by their builders varied from 100 to 300 years. Many of them, however, will not last out even 100 years, and apart from the investments involved, there is a growing prospect of drifting and unstable social conditions for the populations of these irrigated tracts with the capacity of the reservoirs shrinking at their present pace and already impaired for storage of a drought reserve. To quote examples:

- (i) The Gibraltar Reservoir near Santa Barbara, California, was completed

in 1920 and drains 200 square miles, mostly chaparral foot-hills which have suffered from 11 major fires covering 87 per cent. of the area. In its first 5 years the reservoir silted at the rate of 0.95 per annum, then 1.8 for 1925–31, then 2.9 per annum for 1931–4. In terms of acre-feet (an acre 1 foot deep is 43,560 cubic feet) it rose from 160 to 600 acre-feet per annum in this period.

(ii) The Arrowrock Dam on the Boisé River in Idaho had up to 1930 in its first 15 years of service silted up 8,000 acre-feet, which represented in lost storage capacity a large proportion of the original cost. A survey of its catchment area showed the whole of it to be seriously over-grazed, 62 per cent. of the total suffering from distinct sheet erosion.

(iii) The Elephant Butte Dam in the Rio Grande Valley of New Mexico, built in 1919, has silted up 275,000 acre-feet in 18 years, losing 10.4 per cent. of its capacity. The majority of the catchment area is under cattle ranches whose soil is sandy, and wind erosion and grazing are combining to destroy the stability of the soil. It was originally forecast a life of 230 years, but the silting is becoming so pronounced that its useful life is now put at 60 years.

These are impressive figures, and the lesson for other countries contemplating irrigation development is to take early action in ascertaining how far this is going on in their catchments, and arrange for public acquisition and protection of catchment areas wherever these are liable to suffer from misuse by their private owners.

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V. FORESTRY AS A FACTOR IN FARM AND VILLAGE ECONOMY

Shifting Cultivation.

IN summarizing the thirty reports he had received in answer to a questionnaire to district officers in Northern Rhodesia, Professor A. G. Ogilvie states (43): 'The inquiry has elicited certain facts about the modification of the natural vegetation by the natives. The great majority of the people live upon their crops, and most of these are raised in partial clearings of the savannah. The natives are truly men of the trees, apart from which they cannot live. The essential feature of their system of shifting cultivation is the annual felling or pollarding of trees, and the application to the soil of the ash derived from burning the wood on the site of their gardens. The area of woodland cut for

a garden of given size of course depends first upon the luxuriance of the trees, and secondly upon the nature of the practice—whether pollarding or felling. The estimates of the ratio of timber area cut to area of garden vary between 4 : 1 and 10 : 1. The estimates of the period required for recovery of the woods are more numerous, but they are difficult to interpret in view of the inadequate accounts of the vegetation. Several district reports mention rest periods as short as 4 to 5 years; in others these are between 10 and 20, and in Barotse 30 to 35 years. The degree to which the savannah has degenerated under this system of agriculture depends largely upon the density of the population. The native cuts wood for many purposes besides that of manuring his garden. Finally, there is the damage to seedlings and young trees caused by the annual grass fires which sweep the territory, started for various reasons.'

Even if the native could be weaned from his habits, it is not practicable or wise to attempt to do this, because most of these soils are geologically so deficient in phosphorus, that the only means of making them produce crops is by a lavish addition of this and other minerals in a form available to the crop plant. The only feasible way of doing this is by an intense fire reducing large quantities of wood to ash, so that the natives' own method, crude as it is, must be recognized as a perfectly logical one for the individual to use. What is totally illogical is to expect nature to stand up to this treatment with a rapidly increasing population and a progressive degradation of the forest by increasingly frequent visits from the cultivator, besides destructive bush fires, and terribly heavy over-grazing in all the districts free of tsetse fly. The present rate of destruction of forest by shifting cultivation in Nigeria alone is estimated at 1,000 square miles a year.

The only chance of prosperity for such communities—and they are not by any means confined to 'darkest' Africa—is if the administrators realize that the native woodland vegetation must be organized and conserved, and its regeneration processes encouraged to such an extent that each unit of area can continue to carry a definite number of cultivators, beyond which the shifting cultivator population must be drastically pruned out periodically. Whether the surplus members are redistributed to other areas, or encouraged to learn alternative trades, or issued with a vernacular copy of Dr. Marie Stopes, is a local administration problem outside the immediate scope of this paper, which is to emphasize that the whole fabric of primitive agriculture is built upon revegetation by the natural plant cover.

The average administrative officer and indeed also many of the agricultural staff have a sublime and touching faith in the power of nature to reproduce an equally good crop of jungle after each rotation of 'bush fallowing' as occurred originally. The reports summarized by Ogilvie are clear evidence of this. Any forester knows that 4 years will not produce the quantity of fuel or ash required by the cultivator, nor will 10 or 20 years except in the most favourable circumstances of a very humid climate and complete protection in the interval. But unfortunately the management of shifting cultivation is often considered to be outside the forest officer's sphere. Where burning is carried out at short intervals each succeeding visit for burning the jungle produces less per acre, and the cultivator has to destroy correspondingly more acres of forest to obtain one acre of field crops, or else be content with a smaller

amount of ash, in which case he moves on to the next patch earlier. The whole picture is a vicious circle in which the basic needs of nature for her reproductive processes are ignored.

Planning for Shifting Cultivation.

The remedy appears to lie in a scientific approach to the revegetation problem, by setting a definite minimum period of years for the jungle to be regenerated in. This period cannot be discussed as one figure for a huge country any more than a similar figure of grazing incidence can be. Averages over large areas mean practically nothing. The amount of time required varies between districts according to rainfall distribution and intensity, the recurrence of bush fires, the amount of grazing which keeps back the growth, the amount of top soil which has been washed away and lost during the previous cultivations, and the succession of stages through which the natural vegetational cover is gradually rebuilt provided it is not too seriously interfered with. Out of these factors we must see which can be altered or controlled. Grazing is, or should be, controllable. Frequent bush fires have previously been considered inevitable, but it has been shown by fire control work in Nigerian and Indian conditions that some form of regulated burning during the less vulnerable season of the year does effectively reduce the damage done by fiercer conflagrations of the 'fire season'. And the stages of restoration of the plant cover can be materially assisted by timely action, as has been proved by adaptation of the Burma *taungya* methods—namely by getting the cultivators themselves to plant or sow some form of tree crop before they finally leave the area they have cleared for cultivation and move on to their next *taungya*. This has been fully discussed in many numbers of the *Indian Forester* and other forestry publications, as adaptations of this idea have been used with great success in forest operations in Burma and Bengal, and more recently in the United Provinces, where it is being used to create large new reserves of trees which have been selected not for their timber value but because they will augment the fodder supply with tree loppings.

Jungle as a Green Manure Crop.

An interesting and very important development in this direction is the suggestion that the vigorous regrowth of natural forest should be assisted and developed to serve exactly the same principle as herbaceous crops used for green manuring. In Malay it has been shown that some at least of the earlier progressive stages of the grass and shrub development in jungle regrowth can be 'short circuited' artificially by the planting of a small tree, *Vitex pubescens*, which is of no great use in itself, but serves to keep down the grass growth and hasten the establishment of the later stages of mixed tree jungle. This tree actually improves the soil in the process of stifling the grass, which if allowed to establish itself adds appreciably to the total period of restitution. In discussing the wide application of this principle to shifting cultivation as a whole, Mr. J. N. Oliphant writes (44): 'It is, at all events, important that damage to natural vegetation for an ephemeral advantage should be recognized as a serious evil, and that there should be some assignment of scientific responsibility for its correction; for, apart from regions under effective control by forest depart-

ments, natural vegetation has hitherto been "nobody's child". There is, in the writer's opinion, at least some *prima facie* evidence on which to base the belief that methods could be evolved—they would have to be carefully adapted to local vegetative conditions—whereby soils exhausted by shifting cultivation, or by commercial exploitation for the production of economic crops without tillage or manuring, could be restored to productivity cheaply and within quite a short period, say 5 to 10 years, provided that deterioration had not been allowed to proceed too far. The *taungya* method of using abandoned sites of temporary cultivation for growing tree crops is all very well for establishing village wood-lots, but the point is apt to be overlooked that to alternate shifting cultivation with the growing of a slowly maturing crop like timber would mean keeping the cultivators perpetually on the move over a large area, whereas to achieve a settled rural economy the constant aim should be to narrow down the range of their activities to the minimum area compatible with their comfortable subsistence.'

The possibility of applying this principle to local conditions will depend upon an accurate technical knowledge of the component parts of the plant cover, the stages of ecological progress by which it is gradually built up, and the effect of the various factors such as fire, grazing, and rodent and white ant damage upon the seed-crop and seedling development of these stages. This is obviously not a task for any one with large administrative responsibilities and really requires a specialist with local knowledge of the flora, of the habits and limitations of the cultivator, and of the productivity of the forest in supplying the needed material. The working plan for an area based upon his recommendations would have to be prepared on much the same lines as a silvicultural working plan, providing for a guaranteed sustained yield of burnable jungle produce, with a rotation fixed at a corresponding number of years which must on no account be reduced until the local adaptations for speeding up the process have been proved and tried.

The question of erosion of soil from burnt plots both during the cropping stage and subsequently in the earlier stages of revegetation is immensely serious, owing to the very heavy losses from the washing away of the completely unprotected soil which has been thoroughly pulverized by the intense burning. Possible control measures for shifting cultivation erosion are discussed in Chapter VI, as recent work on control measures amongst the primitive shifting cultivation farms of the Tennessee highlands should be of considerable interest to colonial officers. It is obviously quite as vital to stop the rot of soil loss from what is left, as it is to build up afresh an accumulation of jungle fuel.

Woodlots and Shelter-belts in Permanent Agricultural Communities.

Small blocks of woodland on each individual farm are a feature of most really flourishing agricultural communities, because the provision of his own fuel and fence posts is an essential for any farmer who is developing his farm to the fullest capacity of the land. There are many examples in European countries which show how such farm woodlots—and also the slightly more ambitious village forests owned by small communities on a profit-sharing basis—have proved of very great value to their owners, either in helping to pay off rates and taxes, or in providing funds for a church or a school. In very dry climates, or where

wind is a limiting factor in restricting agricultural crops and methods, the main value of such plantations is for protection and amenity, for a few trees round a homestead in an otherwise treeless landscape become a very valuable asset. In more moderate climates the value of small farm plantations is more definitely for the production of fuel and wood products. In areas destitute of any wood fuel supply, such as many parts of India, the fuel need is met by burning cow-dung, and the destruction of one of their main sources of field manure in this way is a very serious drain on their meagre agricultural resources; in such areas—and they are very large ones—the growing of small village woodlots in plantations would serve the twofold purpose of providing wood fuel and releasing the cow-dung for its more legitimate use in the fields. For these reasons it should be of interest to examine the American project now under discussion by the Senate for establishing a large number of farm shelter-belts throughout the arid prairies of the Middle West.

The Great Plains Shelter-belt Project.

The region of arid prairie which extends westwards from the 99th meridian to the foot of the Rockies consists of about 400,000 square miles, varying in altitude from 1,300 to 7,000 feet, but having throughout a dry climate of light summer rainfall and intense summer heat, followed by a very cold winter, and with desiccating winds throughout the year. Temperature extremes vary from —45 degrees F. in winter to 110 degrees in summer in the north, while in the south there is less frost but a correspondingly longer summer. The precipitation average is round about 17 inches for the whole belt, with a tendency to increase eastwards and decrease westwards, while in any one year it may be as low as 8 to 10 inches for the whole tract, as has happened in the summers of 1933 and 1934. The drying effect of the constant winds has been measured as averaging 35 inches of moisture lost in the 6-month summer period (45).

The proposed 'shelter-belt project' is for the formation of a large number of farm shelter-belts, totalling in all some 2,500 square miles of plantation, but distributed throughout the area to provide the maximum shelter for existing farms. The whole of the area was originally covered with an open but efficient stretch of bunch-grass, but the development of 'dry-land' farming in the 1920's, when wheat prices were high and there was a cycle of good rain years, led to vast stretches of it being ploughed up. In the southern section of the belt the climatic conditions are rather similar to the semi-tropic Indian plains of the Punjab and the Deccan, south-west Africa, and the interior of south Australia, and many ecologists consider that the scheme is not feasible.

The only reliable evidence for or against afforestation is in existing trees. From 1878 onwards for some years a Timber-Culture Act to encourage land settlement offered a section of land (160 acres) free on condition that 1/40th of it was planted with trees. The condition was not enforced, and the planting was done badly, if at all, but some trees from these early attempts do remain, having survived several very serious droughts. After this little was done until 1916, when the Department of Agriculture started a co-operative shelter-belt scheme with the farmers to whom it supplied trees, planting plans, and instructions for planting. These have on the whole been fairly successful, and properly tended plantations of well-chosen drought-hardy species can undoubtedly

survive if they are given a modicum of attention. Failures have been mostly due to bad planting, lack of intercultivation, grazing damage, and the abandoning of the farm itself.

When plantations are made in land which is climatically beyond the limit at which both farming and tree growth flourish naturally, it stands to reason that without irrigation the trees will need very careful attention if they are to survive at all. The work on the existing shelter-belts has shown that the attention they most need is intercultivation, in fact the only ones which have successfully withstood the severe tests of the droughts of 1917-20 and 1933-4 are those which have received intercultivation by ploughing in the open ground between the rows of trees. Such intercultivation of course destroys any chance of the plantations forming a leaf-mould litter of their own, and also entails wide planting to enable the plough to be run between the rows, so that the wind gets in and whisks away all the leaf litter. If it were possible to form a dense plantation of some really hardy tree such as *Picea glauca*, and by dint of frequent and heavy thinnings get it established so that intercultivation was not necessary, this would allow the plantation to establish its own soil-building processes. Unless something along this line can be accomplished, the shelter-belt must remain more in the province of gardening than of forestry, and valuable as the contribution may be to the amenity of the farm and as a windbreak, it is unlikely to have any appreciable effect either in building up a new soil profile or in counteracting the general desiccation which has followed the wholesale destruction of the prairie grass cover. It was this natural cover of bunch-grass which had through previous ages maintained a balance between scanty precipitation on the one hand and active evaporation on the other, resisting the desiccating effects of the dry hot winds which have since been obliterating the top-soil by whipping it up from all ploughed surfaces and carrying it away in such quantities as to cause severe dust-storms in many cities along the distant eastern seaboard of the Atlantic.

Given that such plantations can be established in country which is 'sub-marginal' to both forests and unirrigated farming, it is hardly to be expected that large belts of plantations would actually raise the water-table above its normal level where evaporation and transpiration losses must be very large, but they would presumably do more towards preserving it than could the shelter-belts so far established with continued intercultivation between widely spaced rows of trees. Either of them, however, would be an improvement on the present ill chosen farming practices which are responsible for such very widespread desiccation.

Present practice in making these belts is to choose the direction of the worst wind with regard to the protection of farm-house, stockyards, garden, and orchard, and plant a strip up to half a mile long and 130 to 200 feet wide, keeping low bushy shrubs such as the Siberian *Caragana arborescens* and the Russian olive (*Elaeagnus angustifolia*) for the outer windward side and filling up the rest with taller tree species. In the north *Picea glauca* has done better than any other conifer, but in the south the local junipers and *Thuja orientalis* have done well. Of hardwoods the Chinese and American elms, *Acer negundo*, the local cottonwood poplar (*Populus fremontii*), the Osage orange (*Toxylon pomiferum*), and the Russian mulberry (*Morus alba* var. *tatarica*) have all done

very well, and should be worth a trial as likely exotics in other countries where drought-resistant trees are needed for similar undertakings.

Two points in management are worthy of notice. One is that in establishing shelter-belts the United States foresters insist that the land must be leased or definitely taken over by the responsible planting agency, as previous experience has proved that private individuals seldom take sufficient care over the subsequent upkeep of such plantations, even after taking considerable care in establishing them. The other point is the need for fencing against both domestic live-stock and rodents. The more arid the growth conditions are, the less resistant are plantations to withstand the browsing and trampling of live-stock. The need for rodent control may not be essential elsewhere, but a thorough test for possible rodent damage should be carried out to see just how far such protection is necessary.

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VI. FARM EROSION AND ITS CONTROL

Time required to Build Top-soil.

THE average depth of soil in the United States is said to be 7 inches, and this is possibly a fair figure for most other countries as well. How long has this soil taken to make? We do not know precisely, but we can safely say many thousands of years, for soil building is an exceedingly slow process, except in the humid evergreen type of tropical jungle, where the process is a comparatively fast one. Unfortunately what takes so long to build up is only too easily broken down, and many people are for the first time beginning to realize how exceedingly wasteful are the many farming methods which help in its unnecessarily fast destruction. When the true top-soil has been used up or allowed to wash away, the lower horizon of undecomposed subsoil is all that is left, and it is a very poor substitute for the original; it is generally a raw clay, many times less productive, more impervious to rain-water so that less of the rain is returned to underground springs, more difficult to plough, and more easily eroded even than the humus-bearing surface layers. With the cutting down to the subsoil gullyng sets in, and with it the final and complete destruction of the earth's fertility.

Farm Erosion Figures for Bethany, Missouri.

Figures have already been quoted (page 51) to show the comparative rates of erosion for 12 representative soils under grass as compared with the unprotected soil of clean-tilled crops. Taking the Bethany example as typical of very extensive areas in the rolling country of the 'corn belt' of Missouri, Iowa, Nebraska, and Kansas, soils with an average slope of 8 per cent. used continuously for a corn (maize) crop have an annual soil loss of 60 tons per acre,

together with a loss of 27 per cent. of the total precipitation which has run off unused. Compared with this the losses from an exactly similar timothy grass-covered surface are 0.3 ton and 7.7 per cent. With other thick cover crops the figures are still less, e.g. alfalfa (lucerne) gives losses of 0.21 of a ton of soil and 3.41 per cent. run-off, while bare ground with no crops here had a soil loss of 112 tons per acre. These figures are of tremendous significance because they show how directly soil losses react to the amount to which ground is exposed. On the other hand, on the same ground used for a rotation of crops, growing corn every fourth year with wheat and clover occupying the ground in the interval, the loss was reduced to 9.9 tons per acre annually and a water loss of 11 per cent., showing that a good crop rotation is a highly effective method of minimizing both run-off and erosion. These Bethany figures are typical of a tract of 11 million acres, out of which $4\frac{1}{2}$ million have already suffered from sheet washing and $\frac{1}{2}$ million are completely ruined by gullying. Manifestly one cannot always have ground under cover crops or grass, and great acreages must be exposed in the production of the world's food supply, but by better farming methods and local adaptation of the experience gained in the recent intense activity in the United States over erosion control, it should be possible for workers in other countries to realize just where the worst farm erosion is taking place and take steps to stop it. It will be seen that on the basis of these figures, only 20 years of continuous corn cropping will completely exhaust the soil down to stiff impervious clay on all 8 per cent. slopes; for 4 per cent. slopes, 30 years will complete it.

Erosion Survey Results.

These figures are by no means exceptional, but give a good indication of the pace at which very large communities are throwing away their basic agricultural asset of soil. Comparable figures cannot be quoted from other countries, not because this is not happening in them, but merely because similar measurements have not been carried out. The native cultivator in permanent settlements working on carefully levelled fields which have been in use for a very long time has learned how to conserve his soil better, but in almost any other form of cultivation, either of the primitive shifting variety, or where modern machinery is used for ploughing, serious losses are inevitable. Wherever storms of great intensity are experienced they take a heavy toll from all exposed soil in fields and orchards.

Recent soil surveys of the United States as a whole show that 35 million acres have already been destroyed, and out of the total of 350 millions now under cultivation 125 millions have lost all or most of their surface soil, while a further 100 million are eroding seriously, and if not controlled, will lose their top-soil in the same way. These figures paint a really appalling picture, which is being reproduced to some extent at least in every country, although we have no data to prove it except perhaps some river silt load measurements, which of course are not absolute proof of farm erosion, as they may be largely due to over-grazing and to mountain erosion from glaciers and stony mountains. Having realized just how serious the position now is in the United States, it may encourage land-using authorities in other countries to undertake similar measurements, in order to ascertain how far control measures are needed. In

the few cases where data have been collected they are very disturbing, e.g. in the Nyasaland highlands a loss averaging 858 cubic feet of soil per acre per annum is reported. The lack of accurate information is borne out by Mr. T. Eden's masterly summary of the erosion problem from a British imperial point of view (46); out of his 57 bibliographic references, only 9 are from British sources. In a recent summary of all the data which his department has produced up to date, Mr. H. H. Bennett, the director of the Soil Erosion Service of the Federal Government, writes: 'Absorption, run-off, and erosion follow no law of averages. The variables are numerous and of potent influence. Safe procedure in planning engineering works and agronomic programmes for watershed and field protection, flood control, prevention of silting, &c. calls for careful analysis of local conditions of soil, vegetation, slope, and climate. To leave any of these highly pertinent factors out of consideration would be much the same as forgetting to examine the substrata of those places where dams and other heavy structures are to be erected' (47). All of which points to the real need for a more accurate assessment of the erosion situation in the tropical and semi-tropical colonies where the position is already known to be unsatisfactory.

Conjectures without actual measurements are often most misleading. In the United States before their soil erosion survey was undertaken the estimated total figure of erosion losses from fields and pastures of 1,500 million tons a year was thought by many people to be a fantastic and alarmist figure. The recently completed survey based on more accurate data, however, shows, as reported by Mr. Bennett (47*b*), that the loss is actually many times that figure. In an average year the Red Plains region of about 16 million acres in Texas and Oklahoma loses 440 million tons of soil, and in one storm with a 5-inch fall the rich soil of the Texas Black Belt, which is rather similar to the black soils of south India in many ways, lost 23 tons per acre from very slight slopes.

Control Measures.

Any control to be effective must aim at keeping the soil in an absorptive condition rather than erect a series of barriers to check the run-off, though vegetational and earthwork measures will naturally have both effects. The main phases of work fall under one of three headings:

- (i) Manipulation of crops to get the maximum control of run-off, including strip cropping along the contours, the use of crop rotations and cover crops, and reduction of fallow exposure.
- (ii) Manipulation of the ground to break up long slopes by trenching and terracing, and avoiding downhill furrows.
- (iii) Replanning of the individual farm to keep danger points under permanent vegetation, and reforestation of land unsuited for either cropping or grazing.

In the detailed discussion of these operations which follows, it must be remembered that no single one of them used alone can be expected to cure the evil entirely. The cure lies in a judicious use of as many as possible of the various methods; reforestation and replanning of farms is useless if the farmer continues with his old methods on new ground; terracing is worse than useless if it merely throws the accumulated run-off into new channels, as is clearly seen in the 100-year-old terracing efforts in South Carolina.

Strip Cropping.

This consists in dividing up large areas of sloping field or long downhill strips by putting in cross strips of any dense vegetation which will form an effective break to sheet-washing during the period of destructive rainfall. Supplementary feed crops such as clover, alfalfa, or a good hay-making grass are good, and grain crops where these can be maintained in active growth during the rainy period. In the Texas blacklands the annual Sudan grass (*Sorghum sudanense*), oats, sorghum, and similar crops are used in strips a few feet wide between broader strips of cotton and maize. In the steep black hills of the Palouse wheat country in Washington State the huge unbroken wheat-fields can be divided up by strip sowings of winter wheat, which germinates before the spring rains and thus serves to check the wash of the soil, as the summer wheat which forms the bulk of the crop does not come up until these rains are over.

Where irregular width of cultivated strips would make ploughing difficult, giving rise to broken furrows and short rows, this can be avoided by varying the shape and width of the grass strips so that each block of cultivable ground is a parallelogram in which a definite number of furrows can be run right through. Strip cropping is a valuable aid to terracing, and can be used as a temporary check on erosion while terracing is being surveyed and planned (48). In Indian practice the holding power of the earth 'bunds' or ridges which make each tiny field a self-contained water-catchment could be very greatly strengthened if a good hay grass could be grown on the ridges. On an experimental plot in Clarinda, Iowa, parallel strips of corn and alfalfa lost only 1 lb. of soil per acre in 18 months, during which time corn on comparable land but grown according to common practice lost 9 tons of soil per acre. The steeper the slope, the larger a percentage of the field should be devoted to strip crops, but on average slopes under cultivation a quarter of the total area should be quite sufficient.

Crop Rotations.

Even the most primitive agriculture has some sort of crop rotation as its basis, and all farmers are familiar with the need for changing the crops grown on one piece of ground. The usual method is to have a whole field as a unit, and ring the changes with, say, a 4-year rotation of soil-exhausting crops such as cotton or maize with less demanding crops such as peas, beans, barley, oats, or clover, with usually at least one season's fallow. An improvement on this has been adopted in the Tiger River (South Carolina) erosion demonstration area which appears to be worthy of wider application. It is to rotate by strips within the field, not by whole fields, thus $\frac{1}{3}$ rd of each field is under strips of grain or clover, the rest being under the more profitable tobacco, cotton, or maize. Each year a fresh third is taken up for the protective crop, and thus each piece of ground has a chance of recovery in turn. Where the total crop production has an unduly large amount of erosive crops for a district, every effort should be made to readjust a better balance by discouraging the excessive growing of tobacco and corn. In this district of South Carolina the non-erosive crops which are being encouraged are oats, wheat, barley, rye, and sorghum for autumn sowing, lespedeza and sweet clover for spring sowing, soy-beans being of rather doubtful value in checking erosion though of some use as a fertilizer. Lespedeza is much used here as a soil improver with some fodder value, and improved

strains of both annual and perennial forms are used. In the choice of non-erosive crops, a balance of spring and autumn sowings should be maintained, with an emphasis upon those crops which are most efficient as a soil cover during the most destructive rains. In choosing likely erosion control crops, establish the rainfall by months for the locality, then identify the local crops which germinate before the rainy season and give the greatest growth in the wettest month.

Cover Crops.

Almost all types of plantation work where the main crop is an open stand of long-lived bushes, such as tea, coffee, rubber, &c., has its own problem in soil conservation, and in many cases the problem has to some extent been solved already by the use of an efficient low-growing bush or grass which will protect the soil between tree rows, as in the use of *Indigofera endecaphylla* in Ceylon and more recently in Nyasaland. This principle should be more widely applied as a method of soil conservation, and the possibility of applying it to shorter-lived agricultural crops which are good sellers but bad soil protectors. With plants that require constant intercultivation this is perhaps not necessary, but in orchards or field crops that are in long enough to develop a hardened soil, it is very essential to prevent surface washing. In open orchards on fairly steep ground at Santa Paula in Southern California, soil losses of 525 tons per acre were registered for a single storm of $2\frac{3}{4}$ inches of rain.

Bare Fallow and Burning of Stubble.

An outstanding example of a bad fallow system is seen in the Palouse wheat country of the south-eastern and inland portion of Washington States. This has an unusual and striking topography of steep rounded hills of immensely deep black loess, which until recently has been considered entirely wind-blown, as it consists of an endless series of wave-like ridges rising before the prevailing south-west winds. Recent work by Mr. W. A. Rockie, who is now in charge of the Palouse erosion demonstration area, shows (49) that the very steep north-east escarpments of these wave formations are carved out by snow-drift erosion when the warm spring winds break up the late snow-drifts on the cooler face of each hill. The wash from the lower edge of such drifts is very heavy, and carries away a great deal of soil from unprotected fields. This country has been farmed for wheat for nearly 50 years; in early days crops were taken every year, but latterly the yield has fallen and a fallow system has been introduced, in which every second year the area is left bare and ploughing is done during the summer. Unfortunately, in order to get the heavy wheat straw ploughed it is first burned off at the beginning of the summer, which is a long and very dry one, so that the wind erosion of the summer, and the washing of winter rains before the snow blanket is formed, both have free play with the pulverized surface dust (50). The losses during 1933 of soil carried off by rain amounted to 37 tons of soil per acre for untilled hard fallow, 23 tons for fallow seeded to winter wheat (which was too young to be effective in December), 17 tons for pea stubble, 0.7 ton for grass, and 0.5 ton for last year's wheat stubble still undisturbed.

The identical conditions of the Palouse are unlikely to be repeated anywhere else in the world, but the lesson from these figures has a very wide application, as bare fallow and burning of the stubble are common features in a great many

different agricultural systems. The cure in the Palouse is to encourage diversified farming which will create a demand for clover and grass crops so that a regular routine of strip cropping may find a market for its fodder; at present the area is almost entirely without live-stock of any kind except an occasional milk cow, as no beef cattle are kept and all cultivation is mechanical. It is obviously also essential to find some means of stopping the burning of stubble. Where intermittent cultivation leaves bare hill-sides to reclothe themselves gradually during a period of years, as is the custom in the high-level clearings in the Himalayan fir woods at about 10 to 11,000 feet, or in any form of shifting cultivation where the owner does not propose to return immediately, something ought to be done to hasten the revegetation, as has been outlined in Chapter V. A good example of the sort of thing required is in the Californian chaparral scrub forest, where burnt areas sown up immediately after the fire with wild mustard seed have resisted erosion in a marked manner. This plant and *Mysembrianthemum* have been used also for the reclothing of bare road banks along the new highways. If the owners of the fields could be persuaded with the lure of some revenue remission or some other reward to sow up their fields with some such seed when they harvest their last crop, and also to put in cuttings of some easily established local tree species, these areas would be ready for recultivation in a very much shorter time than if they are left to the natural processes of revegetation.

Sod strips.

In field depressions and in the heads of small water-courses which are showing incipient erosion, but which have not reached the stage at which gully control work is necessary, much can be effected by planting out short strips of a good perennial grass sod and leaving them untouched by the plough, unless the soil accumulates behind them so much as to lead to washing at each end of the strip. One very effective way of establishing such small strips is to use sandbags, old feed or 'gunny' bags, with some grass seed thrown into the bag before it is filled with soil and laid in the row of bags. The grass sprouts through the sacking and establishes itself from seed without interfering with the main crop.

Terracing.

The type of low broad terrace generally known in the States as the 'Mangum' terrace is most effective in checking sheet wash on large fields with gentle slopes, where the accumulation of sheet washing effect towards the lower part of each field so often gives rise on cultivated soils to 'shoe-string' patterns of minute gullies an inch or less in depth but a sure sign of heavy soil losses. The Mangum terrace consists of a broad ridge of earth 15 to 24 inches high, ploughed up into a long heap which runs along the hill-side. The base of the terrace varies in width with the slope; the steeper the slope the narrower the base. The usual width for heavy mechanical ploughing with a tractor is about 20 feet at the base, the object in keeping it so flat being to allow continuous cultivation right through the whole field. The terrace is given a very slight slope towards one or other end of the field, the gradient being either uniform throughout at about 2 inches per 100 feet, or increasing on a sliding scale from $\frac{1}{2}$ inch per 100 feet in the first 300 feet up to 4 inches per 100 feet at the lower end. The increasing grade avoids the tendency for the water to pile up near the outlet with danger

of overflows and breaks (51). The use of such terraces in colonial African practice is fully discussed in a Nyasaland publication (52).

The vertical drop between terraces depends upon the character of the soil and the slope of the hill, the usual being a vertical drop between terrace tops of approximately half of the slope of land per 100 feet. The lay-out and levelling measurements for terracing become increasingly important with the increasing size of the individual field, because each additional 100 feet of continuous terrace adds considerably to the accumulation of concentrated run-off in each terrace. It also adds to the engineering problem of handling this run-off at the field edge, when the water has to be got downhill. Where the slopes are very gentle and the soil fairly reliable, simple check-dams of grass sod or twig hurdles are sufficient, but in many places it is necessary either to turf the whole of the lower part of the drainage channel, or else put in a number of concrete or creosoted wooden check-dams. For smaller fields of course the work could be kept very simple and cheap, but the layout of the terraces and the planning of the drainage requires considerably more technical skill than the average farmer or field-worker has.

The Mangum terraces are made by ploughing with a heavy V-shaped drag, pulling the ploughed earth in towards the central ridge of each terrace alignment, which has to be staked out. The weight of the drag of course depends upon the team power, being smaller for animals than for mechanical grading and terracing machines. Where only weak plough oxen are available the same system might be applied on a very much smaller scale, with smaller ridges and more frequent terraces, but the length of continuous terrace must be strictly limited to what can safely handle the heaviest expected rainfall. The layout of terraces must be fixed in the first place by the position of the outlet, and co-operation between neighbours is often needed to provide the best drainage route, and to avoid turning the common boundary line into an ill-chosen outlet.

In the more primitive forms of cultivation, and particularly in shifting cultivation with a soil surface peculiarly liable to heavy washing on even slight slopes, it is essential to teach the cultivator to be 'contour minded'. Even without any other change, the replacement of downhill furrows by furrows along the contour will add appreciably to the life of the soil, particularly where a broad heaped terrace is used as a seed-bed.

Trenching.

As a means of erosion control the trenching of hill-sides too steep for any broad terrace-building may be found useful. An example was seen in the Davis County Flood Control project in Utah, where heavy grazing on steep hill-sides amongst aspen and oak scrub had led to destructive floods, accompanied by mud-flows which engulfed many acres of valuable fruit gardens on the plains away below. In order to restore some sort of plant cover in the danger zones at the heads of the canyons, it was necessary to catch and hold a larger share of snow and rain run-off than the loosened and depleted soil could do as a steep unbroken slope. A road grading plough pulled by a small tractor was therefore used to excavate long contour trenches, which were blocked off into self-contained lengths of 10 to 15 feet by cross-walls, the idea being to prevent an undue accumulation of water at any one point, should a breach or a leak occur. The trench should be narrow and the excavation on the uphill side should be kept

shallow. The ditches must be in sufficient number to prevent concentrating the run-off at any one point and so accelerating instead of checking the erosion. Similar contour ditches, not run together but excavated by hand in separate lengths, have been used for many years in the erosion control work on the Pabbi foot-hills near Jhelum in the Punjab, and have given good results in a particularly arid climate where it is essential to catch and hold some of the infrequent run-off if plant life is to be established at all. Where there is a tendency for slopes of shale or mica-schist to become greasy when wet, however, it is not advisable to crowd a large series of such trenches on to steep slopes, as the extra water held might be the cause of wholesale slipping of the hill-side. Neither of these examples is concerned with farm erosion, but they have both served a useful purpose in expediting revegetation under difficult climatic conditions, and the principle might be of service in repairing the damage done by shifting cultivation on very steep slopes.

Gully Control.

Much has been written in forestry and road-engineering text-books about the various possible alternatives in the construction of check-dams in stream training. It is not proposed to give any elaborate plans or descriptions of types, as experience proves that any material that can be obtained cheaply and plentifully will serve the purpose better than possibly more efficient material which costs more or is more difficult to procure. In field erosion control the use of check-dams and spillways is, or should be, merely a means to an end, namely, that of stabilizing the soil long enough for vegetation to establish itself. This of course does not apply in major stream control projects where engineer works are to be a permanent feature of the work, or in large field contour terraces, where the drainage becomes so concentrated as to require permanent engineering works to look after its disposal.

Where the erosion stage to be checked is of 'shoe-strings' cutting deeper to form definite channel systems, as is often found in sandy loams and most granitic soils, there is not much fear of deep gullies developing and the check-dams can consist merely of dry twigs thrown into the channels and trampled down, or rolled into roughly made bundles and pegged down, the intervals between being short enough to make each obstruction head to be more or less level with the foot of the one next above. The object is to catch as much silt as possible and form a series of level platforms in which sowing and planting can be carried on. By the time the brushwood rots, it is to be hoped that the plant cover will be sufficiently firmly established to need no further help from the check-dams. The effect of wicker-work check-dams with afforestation is well demonstrated in the Biltmore plantations on the Vanderbilt estate in North Carolina, where Dr. C. A. Schenck in 1895 onwards established tree growth on seriously gullied pasture land. There is no trace of those gullies in the present woodland; they have healed completely.

In soils liable to deep gullying and the sloughing in of large blocks of soil and subsoil, such as is common in deep undifferentiated alluvial deposits, or in soft sand-rock underlain by more easily eroded clay, some more elaborate work may be needed, particularly if deep gullies have already been formed. In such cases each small check-dam of local material—slabs of stone, grass hurdles,

rough poles and boards, &c.—should be put in with some care to see that the water dammed up behind it cannot cut through the wings of the structure and so widen the gully channel, even when this is quite a shallow one. Where the gully is deep—say over 8 feet—and with a tendency to form vertical sides, these walls must be broken down from above until a uniform slope has been created at approximately the natural angle of repose for the soil. This is particularly necessary at the gully-head, where each small vertical face is eating back into the undisturbed soil above it; in such places it is useless to expect stability when the surface still has open sores exposed. These gully heads must be broken down to a less dangerous slope before any revetting with check-dams or revegetation is attempted. Many promising attempts at erosion control have failed because this point has not been appreciated. Where the gullies are shallow the breaking down can be effected by hand labour with a pick or beater, but where the gullies are deep it is probably cheaper to plough along the edges. In American practice explosives are frequently used to break down large overhanging banks, but this is expensive and less satisfactory than ploughing which keeps local labour employed and interested.

Drainage.

If gullying has got to the stage where explosives are necessary to break down the gully faces, it may prove cheaper and more effective to alter the drainage system so that the natural catchment area's contribution is diverted from this troublesome channel into some other route where it can do less damage. Where fields receive surface wash from ground such as sheet-rock above them, the provision of storm-water drains or diversion ditches at the top of the field, or at intervals down the slope, should be considered.

Replanning the farm.

The procedure adopted in the States in the newly formed but very active Soil Erosion Service is to single out as a unit for demonstration the catchment area of a river with perhaps 50,000 to 100,000 acres containing a large percentage of eroding farm land which is typical of a larger region. In this project area a set of aeroplane photos are made and an air-map prepared, onto which are traced the farm boundaries from an ordinary survey map. As the 'contact' men persuade farmers to co-operate, each farm is surveyed for erosion troubles, and a 5-year working plan prepared, aiming at withdrawing from cultivation land which is obviously unsuited for it, and the use of strip crops and rotations. Terracing where necessary is being done on a co-operative basis, and reforestation of areas unsuited for either cropping or grazing is arranged for, usually the plants and fencing labour being provided by government and the fencing material cut by the farmer from his woodlot. Any definite readjustment of systems, such as the reduction of excessive live-stock, or the reduction of acreage of erosive crops such as cotton, is planned on an area basis and applied equally for all the farmers in the project area through the medium of the 5-year plan. All waste ground, common grazing, or unallotted woodland in the project area is dealt with at the same time on its merits, and gully control and afforestation too expensive or difficult for the individual farmer to tackle is handled by the Service, using relief labour.



Erosion follows poisoning of vegetation by smelter fumes. Kennett, California



A gully that has grown 80 feet a year in Piedmont farm soil. Tiger River, South Carolina

If these initial demonstration areas are successful—and some of them have already proved eminently so—it is hoped that the educational effect upon the larger neighbouring districts having similar problems will be sufficient to make soil conservation understood and appreciated as it should be by the whole agricultural community.

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VII. OTHER EXAMPLES OF THE MISUSE OF LAND

Smelter Fume Damage.

FUMES from smelters and other industrial plants are occasionally the cause of local but very thorough destruction of the vegetation. A very striking instance is at Kennett on the west of the Sacramento valley in northern California, where copper smelters were at work from 1905 to 1925. To extract the metal the ore was roasted either in the open or in ovens, but in both cases giving rise to liberation of sulphur-dioxide fumes, which hung in the valley pockets, entirely killing out all vegetation in a very few years over an area of 67,000 acres, and seriously affecting the plant life over a further 86,000 acres in an outer zone, the whole forming a long ovoid pattern with the prevailing winds blowing the fumes along more or less parallel valleys. The natural vegetation was chaparral and scrub oak, with a few *Pinus sabiniana* on the border between brush and timber forests, and passing up into scattered *Pinus ponderosa*.

Sheet erosion set in with the destruction of the vegetation, and in 1922 Mr. E. N. Munns measured the erosion as amounting to 400 cubic feet per acre per annum (53). Since then the gully stage has set in on all the steeper slopes and the whole hill-side is crumbling away in a most dramatic manner, 4 to 5 feet of clay subsoil being cut through to bedrock in a single storm (Plate V). The common belief is that such fumes poison the ground, but after 10 years' rest, and with the wholesale removal of all possibly poisoned soil by erosion, there can be no trace of poison left. In fact revegetation can be easily carried out on the present soil surface if the appallingly fast destruction of the surface could only be checked long enough to allow vegetation to take hold. Most of the area is privately owned and is so steep that any system of check-dams would

be prohibitively expensive, so that in the revegetation work now being attempted by the California Forest Experiment Station reliance is chiefly upon willow cuttings stuck obliquely into the shelving banks of gullies.

There are similar smelter fume areas at Bully Hill in northern California, and at Copperhill in Tennessee, and in both places the poisoning of the vegetation has been followed by most spectacular erosion, showing that, no matter what the cause of the destruction of the vegetation may be, the effect leads automatically to unchecked erosion.

Hydraulic Mining.

The valley lands of the American and Feather Rivers plain between the Sacramento Estuary and the Sierras in central California are disfigured by huge accumulations of pebbles, absolutely without any soil and forming utterly sterile dumps which must aggregate many square miles over what ought to be fertile fruit and farm land. These dumps are an enduring monument to the greed of gold-digging enthusiasts. About 1856 the hydraulic method of working came in; it consisted of sluicing away the top soil and the lower soft strata of clay, gravel, and sand which overlie the bedrock on which the gold is usually found (53). The sluicing was done with a monitor with an 8-inch nozzle and an immense charge of water pressure, and after sufficient settling to secure the gold, the whole of the lighter silt and gravel was discharged into the river, only the heavier stone being dumped on the bank. This process went on for some 60 years, and the amount of soil shot into the rivers during that time can only be faintly conjectured. It is on record that one mine discharged into the Feather River in 40 days no less than 300,000 cubic yards of debris. The State Engineer's estimate for one year, 1879, was 53 million cubic yards of material washed into the Sacramento and its tributaries. And to-day, when the gold is all spent—except such as has found its way into certain national treasuries and is apparently likely to remain there!—the best alluvial farm lands are buried under mountains of sterile stone. Let us hope that any further discoveries of gold will be in some rocky mountain where the alternative and more permanent uses of land will not be injured by the resultant scrap-heap.

Road erosion.

The need for providing relief labour for huge armies of unemployed has in many countries been met by the building of a great new system of arterial roads and motoring highways. Many of these are through hilly country, and the rapid drainage from storms falling on a perfectly drained surface and pouring off in great quantities has in many cases set up fresh sources of erosion in the streams which have to carry this new 'peak load'. Further, the level alinement has necessitated building up great banks of 'made earth' which, unless they are assisted, will take some years to reclothe themselves naturally, and meanwhile are a source of heavy silt discharge into local streams (see frontispiece).

In California the Forest Experiment Station has taken up this question with the road engineers, who are now getting the help of the local forest staff in the revegetation of roadside slopes, and have also agreed that any further road alinements affecting forest land should be discussed with the forest officer concerned before they are finally settled. Considerable experience has thus been

gained in a rather specialized form of afforestation work. The long steep slopes of loose earth are very easily broken down by trampling, so material is slung down to the planting squad by means of a simple gravity ropeway running from a scissors or A-frame on the roadside to a convenient tree below, so that trampling is reduced to a minimum. In such soft earth it is not advisable to have any obstruction which will tend to dam back the drainage, so revetting of the slopes is done by burying long bundles of wattle twigs bound up and pegged down with the cuttings of willow and *Baccharis sarothroides*, both of which take root readily from branch cuttings (54). The buried bundles of twigs are put level with the general slope, so they stabilize it without forming an obstruction. The urgent need for any sort of cover to protect the exposed soil is met by line sowings of wheat, barley, wild mustard, and any other suitable local grass or herb which can be depended upon to produce an immediate crop. These serve to hold and consolidate the loose surface until the slower growing plants such as elderberry and *Mysembrianthemum*, which are really more suitable for landscaping, can be established.

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VIII. PUBLIC AND PRIVATE CONTROL OF LAND

Ownership of Grazing Land.

DESPITE the very great differences between India and the United States in many ways, there is a great similarity in their present grazing problems, in that a small proportion of each has been managed more or less efficiently by their respective forest services for the dual uses of forestry and grazing, while the bulk of the remaining public grazing land has suffered so badly from uncontrolled overgrazing as to have deteriorated in value and productive capacity. India has long recognized the need for ensuring a sustained yield policy with regard to her timber forests, and as the United States have recently accepted the principle that all forests and grazing land, both public and private, should be placed on a sustained yield basis (National Resources Board Reports referred to in Chapter I, and National Recovery Act), it would be only logical if the Indian Government accepted the principle that grazing is a national resource which should be conserved and placed upon a sustained yield basis. It is particularly necessary and urgent that the ownership, rights, and management of the village grazing lands, and of the government reserves grossly overburdened with rights, should be overhauled and placed upon a basis of proper management.

The one point in live-stock management on which all in the United States are agreed is the calamitous consequences of free grazing on their public domain, which is an exact parallel of the Indian village grazing system. Government need not own the ground outright to control it effectively, as can be seen in the Australian tenure system. At the time of the New South Wales revision, all pastoral leases were called in by the government and divided into two equal parts, one of which

was returned to the original lessee. With half the land at its disposal, it then organized a new lease system to encourage small owners to get 7-year renewals. The government fixes the classification and fees are charged accordingly, at the rate of roughly eightpence a year for enough ground to keep one sheep, but the rental is put in abeyance during severe droughts, and the tenant gets the profit on any improvements he may make. Co-operative interest under the Australian lease system has been achieved to such an extent that the capacity of the range has improved, supplementary feed has become the rule, water has been developed, and the grade of animals appreciably improved (55). Possible alternatives to the usual permit system should therefore be carefully considered in providing for better control of common land. At the same time government should consider summary curtailment of rights which are being grossly misused, e.g. where a relatively few itinerant foot-hills graziers are allowed to over-graze to the detriment of a larger resident population in the plains, whose water supply and other amenities are likely to suffer in face of continued over-grazing of their catchment areas.

The issue of permits under proper control does ensure forage resources and protection of water sources, and allows a wider choice of seasonal grazing than can be found by the average single lessee, but the lease system—again if properly controlled—offers possibly a better means of educating selected members of a backward community into the advantages of a sounder grazing policy than the old one of ‘first come, first served’.

Organization of Farm Erosion Control.

The opportunity which the United States is now using for teaching farmers the elements of soil conservation is also being used to teach—and, in fact, is based upon—a balanced use of all land. In addition to the farm working plan which has now been adopted as a routine in their demonstration areas, the work includes the reorganization of wood lots, pasture lands, timber reserves, and the possibilities of game conservation. There is no need for government acquisition of land in initiating such a work where the whole land is owned by individual private farmers, and co-operative demonstration methods should be sufficient, but where there is much common land, either of forest or grazing value, and real control is difficult to obtain through local committees, there is an obvious need to arm the organizing agency with powers as a land-holding authority, in order to provide for the redistribution which almost inevitably forms part of a better land use programme.

The use of forests as a means of providing part-time employment for a large part of the agricultural population should be fully explored; local interest in this can often be aroused by constituting a suitable block of forest under the ownership of a town or village as a unit, but its proper management must first be guaranteed. There is no use in handing blocks of government forest over to village communities if they are to be allowed to destroy them, as has actually happened to large areas of forest in the Kumaon Himalayas, where local political pressure forced a precipitate transfer of valuable pine woods to village control, bringing about in a very few years a most lamentable impoverishment of the entire district through accelerated erosion and desiccation. Properly presented, however, the privilege of communal ownership ought to develop more interest and

knowledge in forest conservation, and the same holds equally with community pastures where sound live-stock and dairy farming can be demonstrated to small groups and at the same time contribute to their local food production.

Organization of Regional Land Planning.

In reorganizing land uses the district or region must constitute the unit through which the wider policies of government on crop control, &c., can be made effective. The work has to be intensely localized, and the various central government agencies usually responsible for separate programmes of agricultural and forestry development and engineering projects such as irrigation are not sufficiently closely co-ordinated to meet local needs. Some form of local executive authority which can call upon these various agencies for help and combine their activities into a district plan is therefore essential. An excellent example of the type of control required is seen in the Tennessee Valley Authority, which has grown up more or less fortuitously as a federal government activity independent of the regular land services; a description of its organization may therefore be of interest.

The Wilson Dam at Muscle Shoals is on the Tennessee River near the junction of the states of Tennessee, Mississippi, and Alabama. It was built during the war for munitions manufacture of nitrogen compounds, costing 150 million dollars, and has since been a 'white elephant', but is now to be utilized for the production of cheap fertilizer. Around this nucleus has been built up one of the most ambitious experiments in organized land planning so far attempted in any country, as it aims not only to produce cheap power and fertilizer, but to give a better environment to the two million inhabitants of the Tennessee Valley and its highland drainage basin (56). The area of this catchment is 40,000 square miles and includes part of seven different states. Two other dams are being built farther up the river, one primarily for storage of water and the other to use the moving river water. The Norris Dam on the Clinch tributary is to form a reservoir covering 80 square miles of valley land, and as this will dispossess some 5,000 families of their valley farms, a great deal of resettlement is entailed. The opportunity is therefore being taken to improve the conditions of living, as most of the farming communities here have been dependent on government relief funds during the last few years and are quite unable to make their farms pay their way. Particularly in the highland districts, the farming methods are primitive to a degree, the usual method of growing maize being to burn off the oak and chestnut forest from a steep hill-side. (Fields with an 80 per cent. slope were seen under crops!) They grow crops for 2 or 3 years, then graze the land for a few years before letting it go back to jungle when it is 'wore out', as the farmers expressively describe it. This is, in fact, shifting cultivation in its most primitive and most destructive form, for the forests which have been mutilated in this way should be some of the most valuable hardwood forests in the world, as the natural growth of red, white, and black oaks, poplar, basswood, cherry, black gum, cucumber, black locust, and chestnut was excellent before the era of logging followed by fire and over-grazing set in. There is therefore a tremendous amount of conservation work to be done before these mutilated forests can be made even reasonably productive. There is also a great deal of erosion control work needed, as these steep slopes are cutting away so rapidly

that vast numbers of small check-dams are needed to assist the revegetation process. Part of this is being done to provide labour for the farmers whose land is affected, but most is being done by a group of 4,600 men of the Civilian Conservation Corps, who are also being used for forest fire prevention, reforestation, and forest road development.

The administration of the 'T.V.A.' is in the hands of three directors appointed by the President with the approval of the Senate. The three present occupants are an agricultural engineer, a geographer, and an economist, all of whom have considerable knowledge of local conditions. One of them specializes in the forestry and erosion control, in which he is assisted and advised by the director of the forestry division and a land services committee consisting of the heads of the other allied branches, namely Agriculture (grazing, crops, and 'extension' or educational work amongst the farmers), Industries, Engineering and Geology, Social and Economic, and Land Planning (which is merely for co-ordination of the others' work). The forestry division has a section for planting which handles all farm erosion control work, and its staff includes a large percentage of agricultural engineers, so that the afforestation side is not unduly developed at the expense of other requirements. This type of intensive local organization gives a good chance of close co-operation between engineers and vegetation specialists, which is really a very vital point in any land use development.

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